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REVIEW OF UNCONVENTIONAL COAL MINING CONCEPTS WITH POTENTIAL FOR APPLICATION IN WESTERN CANADA

Report

by

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Mr. R. Kolada
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Dear Mr. Kolada:

Review of Unconventional Coal Mining Concepts
with Potential for Application in Western Canada
DSS Ref. 23SQ23440-4-9197

We have pleasure in submitting our final report for the above project, in one (1) original and ten (10) bound copies, each of which includes an executive summary in English and French.

The report, which includes the comments made during the review of the draft report comprises eight parts. Part 1 provides the background to the study; Part 2 deals with the study methods; Part 3 reviews and describes western Canadian coal mining properties; Part 4 reviews the new and developing technology whilst Part 5 evaluates its application to western Canadian conditions. Part 6 identifies the knowledge gaps and the study conclusions and recommendations are reported in Part 7 and 8 respectively. We have also included in the Appendices relevant technical papers and reports on the site visits and seminar attendances. The data on which the report is based are all in the public domain, or are of a non-confidential nature.

We have found the work on this project extremely interesting and trust that the report will be to your satisfaction. We shall be pleased to answer any questions arising from the report.

Yours very truly,

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EXECUTIVE SUMMARY

EXECUTIVE SUMMARY

1.0 INTRODUCTION

This report was commissioned by the CANMET Coal Research Laboratory in Calgary, Alberta. Its objective was to review all relevant international literature for information, and to document the next generation of potentially viable unconventional underground coal mining schemes that could be developed for application in western Canadian coal seams.

2.0 STUDY METHODS

Data on western Canadian coal properties suitable for development as underground mines was collated from published sources and Monenco's in-house data bank. Data on new and developing systems was obtained through keyword searches of twelve North American and five European data bases, and through contact with some 85 research organizations, companies and mining experts around the world. Responses were received, in varying degrees of usefulness, from 55 of those contacted.

The results from the reviews indicated that no unconventional underground mining coal methods were being researched or developed and reported in the public domain. Most of the work identified, which included the underground mining of sedimentary deposits other than coal, related to new development using existing equipment or methods.

Some forty-eight underground mining properties located in Alberta and British Columbia were identified as potential mines and classified into five categories. The developing mining methods were reviewed and those having potential application to western Canadian conditions were described in detail. These methods were then assessed for applicability to the five selected mining property categories. Suitable mining methods were identified.

Site visits were made in July 1985 to three South African mines which had successfully introduced a more productive version of the Room and Pillar mining system (Rib Pillar Mining) and the opportunity was also taken to attend the First Symposium on Innovative Mining Systems held at the Massachusetts Institute of Technology in November 1985.

3.0 WESTERN CANADIAN UNDERGROUND COAL MINING CONDITIONS

A review of potential underground coal properties in Alberta and British Columbia indicated that between 150 and 200 could support at least a small underground mine. Exploration work had been undertaken on 48 of these within the last ten years and these properties were assumed, for the purposes of this study, to be more likely to be developed in the next twenty years.

The requirement to classify the 48 properties into five categories led to the development of three criteria. These are listed in Table 1.

TABLE 1

Classification of Properties

Category	Seam Thickness (metres)	Gradient (degrees)	Location
I	1.2 - 6.0	0 - 15°	Sub Category A Plains
II	+ 6.0		
III	1.2 - 6.0	+ 15°	Sub Category B Mountains & Foothills
IV	+ 6.0		

The number of properties in each category were:

IA - 14
IB - 4
IIA - 0
IIB - 3

IIIA - 0
IIIB - 12
IVA - 0
IVB - 15

From each of the five active categories, a property was selected as being representative of that category.

The selected properties are:

Category IA	Red Deer, Alberta (TransAlta Utilities)
Category IB	Babcock Mountain, B.C. (Quintette Coal)
Category IIB	Coal Valley, Alberta (Luscar Sterco)
Category IIIB	Willow Creek, B.C. (David Minerals)
Category IVB	Saxon, B.C. (Denison Mines)

Table 2 summarizes the main characteristics for each property.

4.0 NEW AND DEVELOPING TECHNOLOGY

4.1 RECENT DEVELOPMENTS

A number of variations on existing methods were identified. These were divided into two categories: (i) those recently introduced and working in operating mines; and (ii) those which have never been tried or only for very short periods.

In the first category were:

- Yielding Pillar Shortwall System
- Rib Pillar Extraction System
- ESA Shortwall System
- Wongawilli System

In the second category were:

- Underground Auger Mining
- Narrow Hydraulic Room and Pillar Mining
- Thin Seam Borehole Hydraulic Mining
- Radial Mining
- Remotely Controlled Mining

A brief description of each method is presented below.

TABLE 2

Main Characteristics of Selected Properties

Category	IA	IB	IIB	IIIB	IVB
Property	Red Deer	Babcock Mountain	Coal Valley	Willow Creek	Saxon
Location	Plains	Mountains	Foothills	Mountains	Mountains
Coal Type	Sub. Bit. B	Med. Vol. Bit.	High Vol. Sub. Bit. C	Med. Vol. Bit.	Med. Vol. Bit.
Number of Mineable Seams	3	4	3	3	3
Seam Thickness (m)	1.3-3.6	2.5-5.5	5.0-10.0	3.6	2.0-15.0
Seam Gradient	1°	5°-16°	10°-15°	34°-37°	10°-45°
In Situ Reserves (Mt)	1055	127	60	28	330
Roof Strata	SST/SH	SST/CGL	SST/SH	SH/MST	SH/SLT/SST
Floor Strata	MST	SST	SST	MST/SLT	SST/CGL

CGL = Conglomerate
SST = Sandstone
SH = Shale
MST = Mudstone
SLT = Siltstone

4.2 SHORTWALL MINING - YIELDING PILLAR SYSTEMS

This method is being used successfully to mine potash in the United States and in the USSR. The main objective is to allow the roof strata to be lowered following the extraction of the mineral whilst maintaining its integrity, i.e. without fracturing.

The basic application is to the shortwall mining system using continuous miners to excavate the mineral in long rooms, with rows of small pillars left between adjacent parallel rooms (see Section 431). These small pillars gradually crush under the weight of the roof strata and control the lowering of the roof.

The system has particular application where the roof strata must be maintained intact and also to seams where the roof will not cave. Both these conditions are problem areas in western Canada.

The major advantages of this system are:

1. High recovery of mineral
2. Excellent control of roof strata
3. Roof integrity maintained
4. Safe working method
5. Use of rock bolting as support would reduce any bed separation and improve roof integrity

The major disadvantages are:

1. Room width critical
2. Extensive geotechnical investigation required
3. In coal, may be a problem with goaf ventilation
4. In coal, some form of roof support-rock bolting would be required, which could reduce productivity

4.3 RIB PILLAR EXTRACTION SYSTEM

Rib pillar extraction is a generic name coined in South Africa to describe a variation of the room and pillar system which has been developed in that country (from an Australian idea) to increase the ratio of coal produced from depillaring to that produced from development (less efficient mining) and thus improve production and productivity levels and reduce operating costs.

The method consists primarily of developing ribs of coal rather than pillars as is the case with standard room and pillar. This rib pillar serves as a production pillar and is systematically mined on the retreat. Mobile powered supports have been recently introduced to provide stronger and more effective support during the mining of the rib pillar. The method is described in detail in Section 432.

The major advantages of the Rib Pillar Extraction System are:

- Enables high production rates to be achieved with continuous miner equipment and at a lower capital cost than longwall systems.
- High extraction ratios are safely achievable.
- The system is more flexible than a longwall system.
- The system can be applied to geologically disturbed areas.
- Coal production is concentrated, hence supervision can be more effective.
- Coal extraction takes place in a stress relieved area.

The major disadvantages are:

- Extraction of a rib pillar is very time dependent. It must be completed in a continuous manner.
- Requires a good understanding of the geotechnical behaviour of the roof strata.
- Requires roof strata which is cavable.

4.4 ESA SHORTWALL SYSTEM

This new mining system takes the basic principles used in longwall mining cutting, conveying and roof support and utilizes a single set of equipment to develop roadways, open up working faces and mine out the block of coal thus formed. The method incorporates a modified shearer type machine mounted on a special conveyor with powered supports used in both the development roadway drivage and the block extraction. The method, described in detail in Section 433, can be applied to seams of any gradient and has the potential for a high production/development ratio.

The major advantages of the system are:

- Can deal with geologically disturbed areas and can mine isolated areas of coal.
- Same equipment used for development and pillar recovery.
- Low capital cost.

- Early and effective support provided in headings and full support by shields during pillar recovery.
- High mining recoveries possible.
- High productivities possible.
- Very safe mining system.

The major disadvantages are:

- Requires additional equipment to excavate cross-cuts.
- Cutting equipment not mobile like continuous miner and road-headers, thus limiting machine flexibility and requiring dismantling and transportation between working places.
- Requires cavable roof for application of high extraction methods, but can be readily applied to partial extraction.

4.5 WONGAWILLI SYSTEM

This system was developed in Australia to obtain higher productivities and outputs from continuous miner equipment than were possible with the standard room and pillar methods. It is essentially a shortwall mining system with a long, thin pillar of coal providing temporary support, instead of the powered supports normally used in the shortwall method.

The Wongawilli method, which is described in detail in Section 434, is the forerunner of the South African rib pillar method.

The major differences between the South African Rib Pillar method and the Australian Wongawilli method are:

- The rib pillars are considerably longer in the Wongawilli method (110 m vs 24 to 48 m). This is why more coal is lost in unrecovered sections of the rib pillar because it is often too long to mine in one continuous working period.
- The Wongawilli method uses a three entry secondary development, compared with the two entry of the Rib Pillar method. This results in a higher proportion of development coal than depillaring coal with the Wongawilli system, and thus, overall, slightly lower productivities and production.
- Ventilation in the Wongawilli method is through the goaf, whereas with the Rib Pillar method, ventilation roadways equipped with auxiliary fans are provided around the edge of the goaf to also act as gas bleeders.
- The Rib Pillar method makes extensive use of mobile and cross conveyor belts to either eliminate shuttle cars or keep their travelling distance to an absolute minimum.

4.6 CONCEPTUAL OR LITTLE USED SYSTEMS

These systems include:

- AUGER MINING (Section 441) which involves the use of augers to either punch parallel holes in the seam for limited distances from a mine roadway, or applied to the longwall mining system, or for pillar recovery.

- NARROW EXCAVATION ROOM AND PILLAR MINING (Section 442) which is based on the use of very narrow and hence usually self supporting roadways, mined within the seam height to limit dilution and used with conventional or hydraulic transportation.

- HYDRAULIC BOREHOLE MINING (Section 443) as applied to steep thin seams, or thick seams. Holes are bored between two parallel roadways and coal extracted using hydraulic water jet drills, the coal also being transported hydraulically.

- RADIAL MINING (Section 444) refers to a patented method of mining coal around a shaft, and is typical of many ideas which fall short when the mining operational implications are taken into account.

4.7 AUTOMATED MINING

The working and social conditions inherent in the mining industry are such that in times of high employment, the industry has difficulty in maintaining its skilled labour force. It is likely that in the future, people will be even more reluctant to work in underground coal mines, and this should provide the incentive for the use of automation and robotization in the mines.

Mining is a relative latecomer in the utilization of such high technology as automation and robotics in its operation. Current efforts are limited to the introduction of remote control and monitoring systems in underground coal mines which are able to make a direct contribution to improving productivity. The control and monitoring of transportation systems, pumps, ventilation and the underground environment are already commonplace in many mines in Europe and North America.

It is not that mining engineers, who by nature are technically conservative, are unaware of the potential production gains which would be realized with the use of some aspect of high technology in mining. They are certainly aware of the many successful uses of high technology in the space, nuclear, manufacturing and processing industries. There are however several factors unique to mining which tend to impede the rapid introduction of new high technology and robotics into mining. These include:

- the constantly changing geometry of the mine workings and the unpredictability of the working conditions;
- an underground environment which is extremely hostile to equipment, especially control equipment;
- in mining, the robot has to be mobile and work on a constantly changing working face, rather than a stationary robot as used in other industries; and
- acceptance of new equipment and concepts is a long process in mining, since a bad decision can have disastrous consequences on the engineer's and his company's survival.

It must be recognized that the use of robotics in mining will necessitate developments in technology which are far different from those being successfully used in the processing and manufacturing industries, but perhaps may be not too dissimilar from the concepts currently being researched in the USA for mining in space.

One of the major problems to be faced is the lack of knowledge by the engineers involved in mining and in robotics of each others needs, areas of expertise and research and development. A meeting of minds is obviously called for.

Some ideas have already been proposed such as MOLE MINING and TELECHIRIC MINING (Section 445) and although the need for this new technology is unlikely to occur before the end of this century, the long lead time required indicates that it is not too soon to start now to devote research and development effort to robotic mining systems.

5.0 POTENTIAL APPLICATIONS IN WESTERN CANADA

The mining methods identified as having potential application in western Canada were evaluated against the characteristics of the representative mines for the five categories developed for the western Canadian underground mining properties.

This evaluation indicated that certain methods had potential application in western Canadian conditions including both Plains and Mountains/Foothills locations with cavable and non-cavable strata. Table 3 summarizes the basic conditions at each property, and the potentially applicable mining methods.

6.0 KNOWLEDGE GAPS

Knowledge gaps were identified in the following areas:

- Geology - underground coal data base.
- Geotechnology - underground data base.
- Mining Systems - further study required on:
    - production/development ratios
    - continuous coal clearance
    - roof support methods
    - equipment cutting heights

TABLE 3

Less-Conventional Mining Methods with Potential for Western Canada

Category	IA	IB	IIB	IIIB	IVB
Property	Red Deer	Babcock Mountain	Coal Valley	Willow Creek	Saxon
Seam Thickness	1.3-3.6	2.5-5.5	5.0-10.0	3.6	2.0-15.0
Seam Gradient	1°	5°-16°	10°-15°	34°-37°	10°-45°
Location	Plains	Mountains	Foothills	Mountains	Mountains
Special Features	Sandstone Above Seam, Weak Floor, Water	Sandstone Above Seam	-	Variable Quality	Strong Roof and Floor
Mining Method					
Yielding Pillar	X	X			
Rib Pillar*	X	X			
ESA Shortwall	X	X	X	X	
Narrow Room and Pillar		X	X	X	
In-Seam Borehole			X	X	X

* Includes Wongawilli

o	Research Organizations	- reference list of bodies and research work worldwide required.
o	Mining Data	- standardization between data bases necessary.
o	Automatic and Robotics	- summary of worldwide research and development for mining required.

7.0 CONCLUSIONS

The work carried out in this study has resulted in the following conclusions:

1. There are no truly unconventional underground coal mining systems under development and reported in the public domain at the present time.

2. The new developments that are taking place are, more realistically, modifications or adaptions of existing systems, to meet, the specific conditions in specific coalfields.

3. Western Canadian underground coal properties can be classified into a number of categories, currently five, but with a maximum of eight, based on coal seam thickness, gradient and site location data.

4. There are four clear contenders for application to the coal in four of the five categories listed. These are:

    1. Rib Pillar Mining
    2. Yield Pillar Mining
    3. ESA Shortwall Mining
    4. Narrow Excavation Room & Pillar

5. Other methods of somewhat lesser immediate interest include:

    1. Hydraulic Borehole Mining
    2. In the longer term - Remotely Controlled Mining

6. All four major developments require a thorough knowledge of rock mechanics, strata control and the stresses generated by the mining method. This information is not readily available and requires further research, and the detailed investigation of current uses of these developments.

7. Availability of comprehensive data relating to the geological, geotechnical and mining aspects of underground coal properties in western Canada is very poor.

8. Computer data bases are not yet efficient means of accessing data published in mining and related journals.

9. Progress towards remotely controlled mining operations in underground mines is extremely slow and unlikely to result in meaningfull developments during the remainder of the century.

10. Preliminary work on collating information on automation and robotics for application to coal mining should be initiated.

8.0 RECOMMENDATIONS

1. More detailed investigations are required into the basic rock mechanics and mining principles enabling the Yield Pillar, Rib Pillar, Narrow Excavation and ESA Shortwall systems to show promise of improvement over conventional systems.

2. Consideration should be given to developing better reference documents relating to geological, geotechnical and mining data for western Canadian mining properties.

3. A study of the developments of mining equipment associated with services 'elsewhere' underground, i.e., away from the production faces, should be undertaken.

4. Some uniformity in the referencing and accessing of data in computer and data bases is required. Further investigation is required to determine how this can be best achieved.

5. A broader, worldwide referencing of current research work associated with the mining of coal is required. A study is required to determine how this can be best achieved.

6. An information data base should be developed to cover worldwide research, development and usage of automation and robotics methods and equipment for application to coal mining.

9.0 APPENDICES

The appendices contain:

- Report on visits to South African coal mines
- Report on First International Seminar on Innovative Mining Systems
- Reference Technical Papers on Mining Methods
- References
- Lists of Universities, Research Establishments and Mines contacted

RESUME DE LA DIRECTION

1.0 INTRODUCTION

Le Laboratoire de la Recherche Houillère de CANMET à Calgary, Alberta, a demandé l'établissement d'un rapport passant en revue toute la littérature internationale qui se rapporte aux projets d'exploitation souterraine du charbon selon des méthodes originales et potentiellement viables. Le but est d'informer et de documenter la génération suivante des études qui pourraient être développées en vue d'une application aux couches de charbon du Canada occidental.

2.0 METHODES D'ETUDE

L'information portant sur les propriétés houillères du Canada occidental ayant le potentiel de devenir des mines souterraines, a été collationnée à partir de sources publiées, ainsi que des données se trouvant sur place à Monenco. Les informations portant sur les méthodes nouvelles et faisant l'objet de mises au point, ont été obtenues au moyen d'une recherche des mots-clés dans douze bases de données nord américaines et cinq européennes, et en contactant 85 organismes de recherche, compagnies et experts de l'exploitation minière du monde entier. Seulement 55 d'entre eux ont répondu de façon plus ou moins utile.

L'examen de ces réponses indique, qu'officiellement, aucune méthode originale d'exploitation houillère souterraine n'a été rapportée comme faisant l'objet de recherche ou de mise au point. La plupart du travail identifié, y compris l'exploitation souterraine des gisements sédimentaires non-houillers, a rapport à des perfectionnements dans l'utilisation des méthodes actuelles et du matériel existant.

En Alberta et en Colombie Britannique, environ 48 propriétés houillères souterraines ont été reconnues comme étant des mines possibles. Elles ont été classées en cinq catégories. Les méthodes d'exploitation en cours de développement ont été passées en revue et celles pouvant être appliquées aux conditions particulières du Canada occidental sont décrites en détail. Il a fallu ensuite évaluer leur possibilité d'application aux cinq catégories choisies et dégager les méthodes d'exploitation les mieux appropriées.

En juillet 1985, trois mines d'Afrique du Sud ont été visitées. Celles-ci utilisent avec succès une version plus productrice de la méthode d'exploitation par chambres et piliers, l'exploitation par parois allongées (Rib Pillar Mining), et en novembre 1985, l'occasion se présente d'assister au premier colloque portant sur Les Méthodes Innovatrices d'Exploitation Minière à l'Institut de Technologie de Massachussetts.

3.0 LES CONDITIONS D'EXPLOITATION MINIERE SOUTERRAINE DU CANADA OCCIDENTAL

En Alberta et en Colombie Britannique, l'étude des propriétés minières souterraines indique que 150 à 200 d'entre elles seraient capables de supporter au moins une petite mine souterraine. Au cours des dix dernières années, 48 d'entre elles ont été soumises à des travaux de prospection et, pour l'intêret de cette étude, il est très probable qu'elles soient exploitées dans les deux prochaines décennies.

La nécessité de classer ces 48 propriétés en catégories a amené à la mise au point de trois critères énumérés dans le tableau 1.

TABLEAU 1

Classification des propriétés

Catégorie	Epaisseur de la couche (mètres)	Pendage (degrés)	Location
I	1,2 - 6,0	0 - 15°	Sous-catégorie A Plaine
II	+ 6,0		
III	1,2 - 6,0	+ 15°	Sous-catégorie B Montagnes et Contreforts
IV	+ 6,0		

Dans chacune des catégories le nombre des propriétés est:

IA - 14
IB - 4
IIA - 0
IIB - 3
IIIA - 0
IIIB - 12
IVA - 0
IVB - 15

Une propriété a été choisie comme étant représentatrice de chacune des cinq catégories actives.

Les propriétés choisies sont les suivantes:

Catégorie IA - Red Deer, Alberta (TransAlta Utilities)
Catégorie IB - Babcock Mountain, B.C. (Quintette Coal)
Catégorie IIB - Coal Valley, Alberta (Luscar Sterco)
Catégorie IIIB - Willow Creek, B.C. (David Minerals)
Catégorie IVB - Saxon, B.C. (Denison Mines)

Le tableau 2 résume les caractéristiques principales de chaque propriété.

TABLEAU 2

Caractéristiques principales des propriétés choisies

Catégorie	IA	IB	IIB	IIIB	IVB
Propriété	Red Deer	Babcock Mountain	Coal Valley	Willow Creek	Saxon
Location	Plaine	Montagnes	Contreforts	Montagnes	Montagnes
Type de charbon	Sous bitumeux	Bitumeux moyennement volatile	Sous bitumeux fortement volatile C	Bitumeux moyennement volatile	Bitumeux moyennement volatile
Nombre de couches pouvant être exploitées	3	4	3	3	3
Epaisseur de la couche (m)	1,3 - 3,6	2,5 - 5,5	5,0 - 10,0	3,6	2,0 - 15,0
Pendage de la couche	1°	5° - 16°	10° - 15°	34° - 37°	10° - 45°
Réserves in situ (Mt)	1055	127	60	28	330
Couche du toit	GR/SA	GR/CGL	GR/SA	SA/AR	SA/GRF/GR
Couche du sol	AR	GR	GR	AR/GRF	GR/CGL

CGL	Conglomérat
GR	Grès
SA	Schiste argileux
AR	Argile
GRF	Grès fin

4.0 TECHNOLOGIE NOUVELLE ET MISES AU POINT TECHNOLOGIQUES

4.1 MISES AU POINT RECENTES

Les nombreuses variantes des méthodes utilisées reconnues sont classées en deux catégories:

1) celles qui ont été récemment mises en service dans les mines,
2) celles qui n'ont pas encore été essayées ou l'ont été pour de très courtes durées.

La première catégorie comprend:

- la méthode de taille courte à piliers coulissants,
- la méthode d'extraction par parois allongées (Rib Pillar Extraction Mining),
- la méthode de taille courte ESA,
- la méthode Wongawilli.

La seconde catégorie comprend:

- l'exploitation souterraine à foret hélicoïdal (Auger Mining),
- l'exploitation par chambres à cavité étroite et piliers avec transport hydraulique,
- l'exploitation hydraulique par forage d'une couche de charbon mince,
- l'exploitation circulaire,
- l'exploitation commandée à distance.

4.2 EXPLOITATION PAR TAILLE COURTE - LES METHODES A PILIERS COULISSANTS

L'utilisation de cette méthode pour l'extraction de la potasse aux Etats-Unis et en U.R.S.S. donne de bons résultats. L'objectif principal est de permettre que le toit s'affaisse après l'extraction du minerai tout en maintenant son intégrité, c'est-à-dire sans qu'il se fracture.

Cette méthode est en principe utilisée pour l'exploitation de taille courte. Le minerai est extrait dans de longues chambres par des mineurs continus. Ceux-ci laissent des rangées de petits piliers entre les chambres adjacentes (voir section 431). Ces petits piliers s'écrasent progressivement sous le poids de la couche du toit et en contrôlent l'affaissement.

Cette méthode est appliquée, en particulier, lorsque la couche du toit doit être maintenue intacte et dans le cas de couches de charbon pour lesquelles le foudroyage du toit n'a pas lieu. Ces deux conditions posent justement des problèmes dans les mines du Canada occidental.

Cette méthode présente les avantages suivants:

1. rendement/minerai élevé,
2. excellent contrôle de la couche du toit,
3. maintien de l'intégrité du toit,
4. méthode de travail de toute sécurité,
5. l'utilisation du boulonnage de soutènement réduirait la séparation des couches et améliorerait l'intégrité du toit.

Les inconvénients principaux sont:

1. largeur des chambres critique,
2. nécessité d'une recherche géotechnique approfondie,
3. pour le charbon, risque de poser des problèmes d'aérage de la zone foudroyée,
4. pour le charbon, nécessité d'un boulonnage de soutènement du toit ce qui risquerait de réduire la productivité.

4.3 METHODE D'EXTRACTION PAR PAROIS ALLONGEES

(RIB PILLAR EXTRACTION)

L'extraction par parois allongées (Rib Pillar Extraction) est une expression générique inventée en Afrique du Sud pour décrire une variante de la méthode d'exploitation par chambres et piliers. L'idée d'origine australienne a été développée en Afrique du Sud dans le but d'élever le taux de production du charbon par défruitement des piliers comparé à celui d'avancement (qui correspond à une production moins efficace). Ceci permet d'améliorer les taux de production et de productivité tout en réduisant les frais opératoires.

Cette méthode consiste principalement au traçage de longues parois de charbon au lieu des piliers de la chambre standard à piliers. Cette paroi allongée sert à la production puisqu'elle est systématiquement exploitée selon la méthode en rabattant. Des soutènements marchants ont été récemment introduits comme renfort plus efficace au cours de l'extraction de la paroi allongée. La section 432 décrit en détail cette méthode.

La méthode d'extraction par parois allongées (Rib Pillar Extraction System) présente les principaux avantages suivants:

- elle permet d'atteindre des taux de production élevés avec le mineur continu et ceci pour des frais d'installation plus bas que les méthodes de taille longue,

- des taux d'extraction élevés sont atteints en toute sécurité,

- cette méthode est plus souple que celle par taille longue,

- elle peut être utilisée même dans les zones géologiques perturbées,

- la concentration de la production minière rend la surveillance plus efficace,

- l'extraction du charbon a lieu dans une zone de stabilisation.

Les inconvénients majeurs sont:

- l'extraction d'une paroi allongée dépend extrêmement du temps. Elle doit s'accomplir sans interruption.

- Nécessité d'une bonne compréhension du comportement géotechnique de la couche du toit,

- nécessité d'une couche du toit qui soit foudroyable.

4.4 METHODE DE TAILLE COURTE ESA

Les principes de base de cette nouvelle méthode d'exploitation sont ceux utilisés pour la coupe, le transport et le soutènement du toit dans l'exploitation par longue taille. Une seule machine permet le traçage des galeries, l'ouverture des fronts de taille et l'extraction du bloc de charbon ainsi formé. Il s'agit d'une sorte de haveuse modifiée montée sur un conveyeur spécial ayant des soutènements marchants qui sont employés à la fois lors de l'avancement et au cours de l'extraction du bloc de charbon. Cette méthode peut être appliquée pour n'importe quel pendage et est capable d'atteindre un taux de production/développement élevé. La section 433 décrit en détail cette méthode.

Les principaux avantages sont:

- les zones géologiques perturbées peuvent être exploitées de façon satisfaisante ainsi que les zones houillères isolées,
- un seul équipement est utilisé pour l'avancement et l'abattage,
- frais d'installation bas,
- renfort précoce et efficace du soutènement des galeries d'avancement et renfort total par boucliers au cours de l'abattage,
- possibilité de rendements élevés,
- possibilité de productivités élevées,
- méthode d'exploitation en toute sécurité.

Les inconvénients majeurs sont:

- nécessité d'un matériel supplémentaire pour creuser les recoupes,
- l'équipement n'est pas mobile comme le mineur continu ou les machines d'avancement (road headers). Ainsi, cette machine offre une souplesse limitée car elle doit être démontée et transportée entre les lieux de travail.
- Nécessité d'un toit qui soit foudroyable lors de l'utilisation des méthodes d'extraction à taux élevé mais possibilité d'utilisation immédiate pour une extraction partielle.

4.5 LA METHODE WONGAWILLI

L'Australie a développé cette méthode, utilisant le mineur continu, pour obtenir un rendement et une productivité supérieurs à ceux réalisés par les méthodes conventionnelles de chambres à piliers. C'est une méthode essentiellement de taille courte. Un pilier long et étroit sert de soutènement temporaire au lieu des soutènements marchants habituellement employés pour la taille courte.

La méthode Wongawilli est le précurseur de celle à parois allongées (Rib Pillar Method) d'Afrique du Sud. La section 434 décrit en détail cette méthode.

Les différences principales entre la méthode d'exploitation des parois allongées (Rib Pillar Method) d'Afrique du Sud et la méthode Wongawilli australienne sont les suivantes:

- les parois allongées de la méthode Wongawilli sont considérablement plus longues (110 m versus 24 à 48 m). C'est pourquoi la perte de charbon est plus importante dans les sections non-productrices de la paroi allongée car son exploitation en une seule étape ininterrompue est beaucoup trop longue.

- La méthode Wongawilli possède des galeries secondaires à trois voies, comparée à celles à deux voies de la méthode aux parois allongées (Rib Pillar Method). Par conséquent, la proportion de charbon produite par la méthode Wongawilli est plus importante pour l'avancement que pour l'abattage et ceci résulte en une production et un rendement légèrement plus bas.

- Pour la méthode Wongawilli, l'aérage se fait par la zone foudroyée alors que pour la méthode à parois allongées (Rib Pillar Method) les voies d'aérage sont équipées de ventilateurs auxiliaires situés sur le pourtour de la zone foudroyée. Ils jouent aussi le rôle d'aspirateur du grisou.

- La méthode à parois allongées (Rib Pillar Method) utilise des conveyeurs mobiles et entrecroisés à bande de façon extensive, afin d'éliminer les camions-navette ou de réduire leur parcours au minimum.

4.6 METHODES CONCEPTUELLES OU PEU UTILISEES

Elles comprennent:

- l'exploitation à foret hélicoïdal (Auger Mining) utilise des forets hélicoïdaux soit pour creuser des trous parallèles dans la couche afin de réduire la distance à la galerie principale, soit dans le cas de la méthode d'exploitation de taille longue, soit pour le défruitement des piliers.

- L'exploitation par chambres à cavité étroite et piliers (voir section 442). Ce procédé utilise des galeries très étroites et, par conséquent, ne nécessitant pas de soutènement. L'abattage s'effectue dans les hauteurs limites de la couche afin de réduire la dilution. Le charbon est transporté de façon conventionnelle ou hydrauliquement.

- L'exploitation de forage hydraulique (voir section 443). Elle s'applique à des couches minces à fort pendage, ou à des couches épaisses. Les puits sont forés entre deux galeries parallèles et le charbon est extrait par des perçeuses à jet d'eau sous pression. Le charbon est, là aussi, transporté hydrauliquement.

- L'exploitation circulaire (voir section 444) se réfère à une méthode brevétée d'extraction circulaire du charbon autour d'un puits. C'est une des nombreuses idées qui s'effrondrent dès qu'il s'agit de tenir compte de ce qu'elles impliquent au niveau de la réalisation.

4.7 EXPLOITATION AUTOMATISEE

Les conditions sociales et de travail inhérentes à l'industrie houillère sont telles, qu'en période d'emploi optimum, il est difficile de maintenir une main-d'oeuvre qualifiée. Il est probable qu'à l'avenir, les gens seront encore plus hésitants lorsqu'il s'agira de travailler dans des mines souterraines, et ceci devrait stimuler l'usage des machines et des robots.

Une technologie aussi poussée que l'automatisation et la robotique, a fait une entrée plutôt tardive dans l'industrie houillère. Les efforts actuels se limitent à l'introduction des systèmes de contrôle et de commande à distance. Ils ont contribué directement à une amélioration de la productivité. Dans la plupart des mines d'Europe et d'Amérique du nord, les systèmes de contrôle et de commande à distance du transport, des pompes, de l'aérage et de l'environnement souterrain sont déjà d'usage courant.

Les ingénieurs des mines sont par nature conservateurs dans leur adoption de techniques originales. Ils sont, cependant, conscients des gains de production qui pourraient être obtenus grâce à l'emploi de certains aspects de cette technologie avancée. Ils n'ignorent pas les nombreux succès réalisés grâce à cette technologie dans l'industrie spatiale, nucléaire, de manufacture et de traitement. Cependant, plusieurs facteurs particuliers à l'industrie houillère tendent à empêcher l'introduction de cette nouvelle technologie et de la robotique. Ceux-ci sont:

- la géometrie constamment changeante des chantiers et le caractère imprévisible des conditions de travail,

- un environnement souterrain qui est extrêmement hostile aux équipements et en particulier ceux de contrôle,

- dans l'industrie houillère, le robot doit être mobile de façon à travailler sur un front de taille changeant alors que, dans les autres industries, il est stationnaire,

- dans l'industrie houillère, l'acceptation d'un matériel et de concepts nouveaux est un processus qui demande du temps car une mauvaise décision peut avoir des conséquences désastreuses pour la survie de l'ingénieur et de sa compagnie

Il faut reconnaître que, dans l'industrie houillère, la robotique nécessitera des mises au point technologiques bien différentes de celles auxquelles sont parvenues les industries de traitement et de manufacture. Elles seront peut-être quelque peu semblables aux concepts actuellement à l'état de recherche aux Etats-Unis pour l'exploitation extraterrestre.

Un des problèmes majeurs est le manque de connaissance, des ingénieurs des mines et de la robotique, des besoins de chacun, de leurs domaines d'expertise, de recherche et de perfectionnement. Il faut évidemment que les esprits se croisent.

Certaines idées ont déjà été proposées telles que l'exploitation MOLE et l'exploitation TELECHIRIQUE (voir section 445). Bien que la nécessité de cette nouvelle technologie ne se fera pas sentir avant la fin de ce siècle, l'avance nécessaire indique qu'il n'est pas trop tôt pour s'adonner à la recherche et à la mise au point des méthodes d'exploitation par la robotique.

5.0 POSSIBILITES D'APPLICATION AU CANADA OCCIDENTAL

Les méthodes d'exploitation reconnues comme pouvant être adaptées au Canada occidental ont été évaluées par rapport aux caractéristiques des mines représentatrices des cinq catégories choisies pour les propriétés d'exploitation souterraine du Canada occidental.

Cette évaluation indique que certaines méthodes peuvent être appliquées aux conditions du Canada occidental, y compris la Plaine et les Montagnes/Contreforts, que la couche houillère soit foudroyable ou non. Le tableau 3 résume les conditions de base de chaque propriété et les méthodes d'exploitation susceptibles d'être appliquées.

6.0 LES LACUNES SCIENTIFIQUES

Des lacunes existent dans les domaines suivants:

- géologie : base de données du charbon souterrain,
- géotechnologie : base de données souterraines,
- méthodes d'exploitation : des études approfondies sont nécessaires sur:
  - * les taux de production/développement,
  - * le déblayage continu du charbon,
  - * les méthodes de soutènement du toit,
  - * les hauteurs de coupe des équipements.
- organismes de recherche : nécessité d'une liste de référence des organismes et des travaux de recherche dans le monde entier.
- données d'exploitation : nécessité de normes standards adoptées par toutes les bases de données.
- automatisation et robotique : nécessité d'un résumé de la recherche des mises au point d'exploitation.

TABLEAU 3

Méthodes d'exploitation plus ou moins originales pouvant être appliquées au Canada occidental

Catégorie	IA	IB	IIB	IIB	IVB
Propriété	Red Deer	Babcock Mountain	Coal Valley	Willow Creek	Saxon
Epaisseur de la couche (m)	1,3 - 3,6	2,5 - 5,5	5,0 - 10,0	3,6	2,0 - 15,0
Pendage	1°	5° - 16°	10° - 15°	34° - 37°	10° - 45°
Location	Plaine	Montagnes	Contreforts	Montagnes	Montagnes
Traits particuliers	Grès immédiatement adjacent à la couche de charbon, sol fragile, eau.	Grès immédiatement adjacent à la couche de charbon.	-	Qualité variable	Toit et sol robustes
Méthode d'exploitation					
Piliers coulissants	X	X			
Parois allongées *	X	X			
Taille courte ESA	X	X	X	X	
Chambre à cavité étroite et piliers		X	X	X	
Forage intérieur de la couche			X	X	X

* Wongawilli inclus

7.0 CONCLUSIONS

Le travail entrepris par cette étude amène aux conclusions suivantes:

1. Il n'y a actuellement pas de méthode réellement originale d'exploitation souterraine du charbon qui soit officiellement en cours de mise au point.

2. Les mises au point nouvelles effectuées en ce moment sont, de façon plus réaliste, des modifications ou adaptations des méthodes existantes pour répondre aux conditions spécifiques d'une zone houillère donnée.

3. Les propriétés houillères souterraines du Canada occidental se classent en un certain nombre de catégories, pour le moment, cinq ont été choisies mais elles peuvent aller à un maximum de huit en fonction de l'épaisseur de la couche, du pendage et des données concernant l'emplacement du chantier.

4. Parmi les cinq catégories énumérées, les quatre méthodes suivantes se disputent la place pour ce qui est d'une application à l'exploitation du charbon:

    1. l'exploitation par parois allongées (Rib Pillar Mining),
    2. l'exploitation par piliers coulissants,
    3. l'exploitation de taille courte ESA,
    4. l'exploitation par chambres à cavité étroite et piliers.

5. D'autres méthodes d'intêret moins immédiat sont:

    1. l'exploitation par forage hydraulique,
    2. à long terme - l'exploitation commandée à distance.

6. Les quatre mises au point principales demandent une connaissance approfondie de la mécanique des roches, du contrôle des couches et des tensions provoquées par la méthode d'exploitation. Cette information n'est pas immédiatement disponible et nécessite des recherches supplémentaires et une investigation détaillée des emplois actuels de ces mises au point.

7. Les données étendues portant sur les aspects géologiques, géotechniques et d'exploitation des propriétés minières souterraines du Canada occidental ne sont pas facilement disponibles.

8. Les bases de données informatiques ne sont pas encore des moyens efficaces d'accès à l'information publiée dans les revues d'exploitation minière ou apparentées.

9. Les progrès réalisés dans l'utilisation des méthodes d'exploitation à distance sont extrêmement lents et il est peu probable que des résultats significatifs soient obtenus d'ici la fin de ce siècle.

10. Il faudrait commencer le travail préliminaire de rassemblement des renseignements sur l'automatisation et la robotique pouvant être utilisés dans l'industrie du charbon.

8.0 RECOMMANDATIONS

1. Des recherches plus détaillées devraient être entreprises portant sur les principes de la mécanique des roches et ceux des exploitations originales. Il s'agirait de démontrer que ces dernières - à piliers coulissants, parois allongées (Rib Pillar Mining), chambres à cavité étroite et piliers, et de taille courte ESA -

permettent une amélioration par rapport aux méthodes conventionnelles.

2. Il faudrait tenir compte de la nécessité de développer des documents de référence de meilleure qualité portant sur les données géologiques, géotechniques et houillères des propriétés minières du Canada occidental.

3. Il faudrait entreprendre une étude des mises au point des équipements associés aux services souterrains autres, c'est-à-dire ailleurs qu'aux fronts de production.

4. Une uniformité du système de référence et d'accès à l'information des ordinateurs et des bases de données est nécessaire. Une recherche supplémentaire devrait déterminer comment y parvenir.

5. Un système de référence mondial, plus large, comprenant tous les travaux de recherche actuels associés à l'exploitation du charbon est nécessaire. Une étude devrait déterminer comment y parvenir.

6. Une base de données d'information devrait être mise au point qui comprendrait les travaux internationaux de recherche, les mises au point et l'utilisation des méthodes d'automatisation, de robotique et des équipements applicables à l'industrie houillère.

9.0 APPENDIXES

Les appendixes comprennent:

- un rapport des visites de mines de charbon d'Afrique du Sud,
- un rapport du premier colloque international sur Les Méthodes Innovatrices d'Exploitation Minière,

- des documents de référence technique portant sur les méthodes d'exploitation,
- des références,
- la liste des universités, établissements de recherche et mines contactés.

UNCONVENTIONAL COAL MINING CONCEPTS

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PART 1 - INTRODUCTION

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1.0 INTRODUCTION

This study was authorized in January 1985 by the Canadian Department of Supply and Services on behalf of the Department of Energy, Mines and Resources, CANMET, Coal Research Laboratory, Calgary, Alberta.

Authorization to proceed was based on a proposal from Monenco Consultants Limited dated 28 September 1984 from which the following objectives and scope of work were defined and agreed.

1.1 OBJECTIVE AND SCOPE OF WORK

111 OBJECTIVE

The defined objective of this program is to review all relevant international literature for information and document the next generation of potentially viable underground coal mining schemes that could be developed for application in western Canadian coal seams.

112 SCOPE OF WORK

The scope of work for this project comprises the following five activities:

.1 Specify five or fewer reference coal seams and geological settings that represent underground coal mining conditions in western Canada.

.2 Using the reference seams as a guide, search all relevant international technical literature for new mining concepts that could be more economical than the best of current methods in use but excluding in-situ schemes.

.3 Reference and abstract the more relevant papers and identify centres of excellence committed to research on unconventional coal mining methods.

.4 Examine in more detail and discuss the merits of no more than five schemes that might be applied in western Canada in the next two decades.

.5 Identify knowledge gaps and outline additional work that could be undertaken to address these technological requirements.

PART 2 - STUDY METHODS

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2.0 STUDY METHODS

Coal is mined from underground deposits in many countries of the world. However the main producing countries are the USA, USSR, China, U.K., Western Germany, France, Canada, South Africa, Australia and India. The search for new or developing underground coal mining methods was therefore concentrated on these countries.

Following the award of the contract, a meeting between CANMET (Coal Research Laboratory Calgary) and Monenco finalized the strategies for the study; indicated that, where possible, study efforts should be directed towards items 4 & 5 of the scope of work (section 112); and, agreed the study methods.

At the start of the contract, the intention was to identify new and unconventional methods of mining coal underground. In this context, the definition of 'unconventional' was taken to mean mining methods which bear little or no relation to mining methods currently being used to produce coal from underground mines. This definition was intended to exclude such methods as longwall, shortwall, room & pillar and hydraulic mining.

However, as the study proceeded, and the data search produced results, it became obvious that in the present economic climate, no unconventional underground mining methods were being researched or developed, or if they were, knowledge of them was not in the public domain.

The focus of the study was therefore changed to concentrate on the development trends of current mining methods and on the mining methods used in other sedimentary minerals, which might have application to the mining conditions present in the Western Canadian Coalfields.

2.1 WESTERN CANADA UNDERGROUND MINING CONDITIONS

Data on potential underground coal mines in western Canada (Alberta and B.C.) was collated from published government and industry sources and from Monenco's in-house data banks. A simple classification was developed, and utilized to group the mines.

2.2 NEW AND DEVELOPING TECHNOLOGIES AND SYSTEMS

Data was obtained in two stages. Firstly, through keyword searches of mining and other computer data bases, including the following:

North America:	MNT; OON; COMPENDEX; MINSYS; NTIS; QL; EI ENGINEERING MEETING; USGPO; COALPRO; SCISEARCH; INSPEC; US PATENTS.
Europe:	MTCH; IMM; PASCAL; IEA COAL; GEOLINE.

Some considerable difficulty was encountered in extracting information from such a wide variety of databases. This is in line with our previous experience and appears to relate to differing standards for key-wording extracts, and quite often vastly different formats for storing and retrieving data.

Secondly, through contact made with approximately 85 research organizations, mining companies and known experts in the field of mining technology. Responses were received from 55 of those contacted.

2.3 DATA ABSTRACTION

The relevant acquired data was catalogued, key data abstracted, and systems and technologies of interest identified and researched in more detail. Organizations involved in developing new methods, systems and technologies were listed.

2.4 APPLICATION OF TECHNOLOGY

It proved possible to allocate the potential underground coal mines into five groups. A representative property was selected from each group, and the developing technologies identified previously were reviewed for potential application to each selected property. The merits and demerits of each were examined and the most attractive conceptual schemes identified.

2.5 KNOWLEDGE GAPS

As with any new technology the ones highlighted and presented in this study are not necessarily complete or ready for immediate use with a high level of confidence. Consequently a brief review was made to determine what was required to bring the systems to a level of confidence at which they would become attractive to mining companies for further development and use.

2.6 SITE VISITS

As a result of the investigations made in the course of the study, a relatively new mining system was identified which appeared to offer high rates of coal recovery in the mine in strong roof conditions and where the risk and capital cost of longwall mining were unacceptable. Since many western Canadian properties have strong roofs and are not suitable for longwall mining, it was agreed by the Scientific Authority that a visit should be made to the SASOL Collieries in S. Africa which are successfully working this new system (Rib Pillar Extraction) as well as the conventional room & pillar and longwall systems. The visit took place from 8 July to 12 July 1985 and is reported in detail in Appendix A.

2.7 SEMINARS

As the report was being finalized, notice was received concerning the First International Symposium on Innovative Mining Systems to be held at M.I.T., Cambridge, Massachusetts, and sponsored by the newly established Centre of Innovative Mining Systems. It was agreed that attendance at the Seminar would be of benefit to the study, and a report on the proceedings of the November 4-5, 1985 meeting is included as an addendum (Appendix E).

PART 3 - WESTERN CANADIAN UNDERGROUND COAL MINING CONDITIONS

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3.0 WESTERN CANADIAN UNDERGROUND COAL MINING CONDITIONS

3.1 GENERAL ASSESSMENT

Coal in western Canada underlies a considerable part of Alberta, intermittently throughout Saskatchewan and across British Columbia from its eastern border to Vancouver Island (Figure 3-1). An initial overview of all possible underground coal properties in Alberta indicated that somewhere in the region of 150 properties could support at least a small underground mine. As a similar overview of potential properties in British Columbia produced many additional locations for new underground mines, it was obvious that it would not be practical in this type of study to gather and analyze information on every property. An underground mineable property was considered to be one where coal was present at depths greater than 100 metres.

It was therefore decided to limit the selection of the properties to those (48) on which some exploration work had been undertaken in the last ten years, since it was assumed that such properties were more likely to be developed in the next twenty years.

3.2 PROPERTY CLASSIFICATION

A brief review of such basic charateristics as seam thickness, gradient, depth and location was made. This suggested that, within the terms of the scope of work of this study, the simplest classification could and should be made on the basis of seam thickness and gradient. It is also well known that, structurally, there is a distinct difference between the coal seams located in the Alberta Plains, and the coal seams located in the Alberta and B.C. Foothills and Mountains regions. A further subdivision was made to identify this difference.

The four categories proposed and used are given in Table 3-1.

TABLE 3-1

Classification of Properties

Category	Seam Thickness (metres)	Gradient (degrees)	Location
I	1.2 - 6.0	0 - 15°	Sub Category A Plains
II	+ 6.0	0 - 15°	
III	1.2 - 6.0	+ 15°	Sub Category B Mountains & Foothills
IV	+ 6.0	+ 15°	

The rationale for choosing these parameters is given below:

.1 Seam Thickness

The majority of mining equipment currently in use in coal mines around the world is presently limited to a maximum cutting height, in a single pass, of between 4.5 and 5.5 metres. A figure of 6 metres therefore represents a reasonable cut off for the seam thickness criteria. In the lower thickness category, a lower limit of 1.2 metres was also selected because it is not normally considered economical to mine below this height by underground mining methods.

.2 Gradient

Mining equipment can be divided simply into mobile and non-mobile types. Mobile equipment is not normally used on gradients greater than 12°-14° although non-mobile equipment can operate in the range from 0° to in excess of 70°. An arbitrary cut off of 15° was selected to differentiate between the two different types of equipment.

.3 Location

Plains coals are generally less structurally disturbed by faults, folds and similar geological features than the Foothills or Mountains coals. Thus, since these features can have a significant effect on the success of the mining method, and even though seam thickness and gradient may be similar, we believe that the extra distinction is relevant.

Whilst it would appear that a total of eight categories have been identified, in practice only five are utilized since there are no plains coals among the properties selected which fall into categories IIA, IIIA & IVA.

It must be appreciated, however, that this classification is very basic. Many other factors need to be taken into account in assessing the viability of a mine and the methods by which it could or should be worked. Other factors referred to include:

- nature of strata above and below the coal seams,
- coal quality,
- depth from surface,
- presence of water,
- site location and access to infrastructure,
- economics.

The question of ranking the selected properties with respect to their economic viability or attractiveness was also raised. This is a more complex judgment than can be attempted in this state of art review study, requiring development of geology, coal quality, mine planning and equipment selection, capital and operating cost estimates and financial and economic analyses.

3.3 PROPERTY SELECTION

In section 3.1, it was indicated that there are between 150 and 200 mining properties in Alberta and B.C. which could be broadly considered as underground mineable. However, when the criteria of the state of exploration is applied, this number reduces to less than fifty.

We have listed in Table 3-2, the 48 properties which we have identified as having some prospects, however remote, of being mined in the next twenty years. These properties have been classified in accordance with the categories selected previously.

As can be seen from Table 3-2, these potential underground coal mining properties have widely varying mining conditions that will necessitate the use of widely varying mining technology. It is also likely that more than one mining system or technology (including present conventional systems) could be applied to each property. We have reviewed the developing systems and technologies in Part 4 and evaluated their applicability to the mines listed above in Part 5 both of which follow.

From each of the five groups, we have selected one property as being typical of that group.

The selected properties are:

Category IA	Red Deer, Alberta (TransAlta Utilities)
Category IB	Babcock Mountain, B.C. (Quintette Coal)
Category IIB	Coal Valley, Alberta (Luscar Sterco)
Category IIIB	Willow Creek, B.C. (David Minerals)
Category IVB	Saxon, B.C. (Denison Mines)

The locations of these properties are shown in Figure 3-2.

TABLE 3-2

Prospective Underground Mines In Next 20 Years

Property	Owner	Mining Conditions
CATEGORY IA		
Kipp	Petro-Canada	Flat seams to 1.8 m thickness.
Innisfail	Petro-Canada	Flat seams up to 1.8 m thick.
Picture Butte	Pre-Cambrian Shield Resources	Fairly flat seams 1.8 m thick.
Buffalo Hills (Vulcan)	Seagull Resources	Fairly flat seams to 3.9 m thick.
Innisfail	TransAlta Utilities	Fairly flat seams up to 1.8 m thick.
Drumheller	TransAlta Utilities	Fairly flat seams up to 3.6 m thick.
Red Deer	TransAlta Utilities	Fairly flat seams up to 3.6 m thick.
East Coulee Mine (Drumheller)	Centry Coals Ltd.	Fairly flat, 1.8 m thick seams.

TABLE 3-2 (Cont'd)

Property	Owner	Mining Conditions
CATEGORY IA (Cont'd)		
Shaughnessy	Fording Coal	Fairly flat lying seams to 1.8 m thick.
Star Key Mines	Genstar	Fairly flat lying 1.8 to 2.4 m thick seams.
Cooking Lake	Several	Fairly flat lying seams to 3.4 m thickness.
Wizard Lake	Several	Fairly flat lying 2.4 m thick seam.
Highvale - Low Water	TransAlta Utilities	Fairly flat lying seams to 5.1 m thickness.
Chancellor	Several	Fairly flat lying seam 1.8 m thickness.

TABLE 3-2 (Cont'd)

Property	Owner	Mining Conditions
CATEGORY IB		
Sukunka (B.C.)	B.P. Resources	Fairly flat 2.4-3.0 m thick seams.
Bonnet Plume	Pan Ocean	Fairly flat seams to 2.4 m thick.
Babcock Mountain (B.C.)	Quintette Coal	Multiple seams to +6 m thickness dipping 10 to 50°.
Quinsam Mine (B.C.)	Weldwood Industries	Seams to 3 m thickness dipping to 15°.

TABLE 3-2 (Cont'd)

Property	Owner	Mining Conditions
CATEGORY IIB		
Coal Valley	Luscar (Sterco)	Seams 5 to 10 m thick dipping at 10 to 15°.
Cinnabar Peak Mines	Cinnabar Peak Mines Ltd.	Seams to 2.4 m thickness dipping from 10 to 35°.
Fall Creek	Dome	Two seams 2.5 and 3.6 m thickness dipping to 20°.

TABLE 3-2 (Cont'd)

Property	Owner	Mining Conditions
CATEGORY IIIB		
Monkman (B.C.)	Petro-Canada	Multi-seams dipping 15 to 25°. Thickness to 6 m.
Ram River	Petro-Canada	Seams to 3 m thick dipping 10 to 20°.
Grassy Mountain	Consol/Home Oil	Seams to 3 m thickness dipping from 10 to 50°.
Ram River	Consol/Home Oil	Seams to 3.9 m thickness dipping from 10 to 30°.
Nordegg	Consol/Home Oil	Seams to 3 m thickness dipping from 10 to 20°.
Adanac	Consol/Home Oil	Seams to 3 m thickness dipping from 10 to 50°.
Bowron River (B.C.)	Norco Resources Ltd.	Seams to 6 m thickness dipping from 15 to 30°.
Mount Spieker (B.C.)	Ranger Oil	Seams to 3.6 m thickness dipping 15 to 30°.

TABLE 3-2 (Cont'd)

Property	Owner	Mining Conditions
CATEGORY IIIB (Cont'd)		
Bullmoose (B.C.)	Teck Corporation	Seams to 6 m thickness dipping 15 to 35°.
Willow Creek (B.C.)	David Minerals	Seams to 3.6 m thickness dipping 20 to 30°.
Belcourt (B.C.)	Denison Mines	Multiple seams to +6 m thickness dipping 10 to 40°.
Elk River Mine (B.C.)	Elco Mining Co.	Multiple seams to +6 m thickness, dipping 10 to 45°.

TABLE 3-2 (Cont'd)

Property	Owner	Mining Conditions
CATEGORY IVB		
Hat Creek (B.C.)	B.C. Hydro	Massive, several +30 m thick seams located in a large dipping syncline.
Copton (West)	Amax/McIntyre	Steep seams to 6 m thick seams.
Cardinal River	Consol/Luscar	Single 6 to 30 m thick seam very steeply pitching.
Mountain Park/Cadoman	Consol/Luscar	Seams to 7.5 m thickness dipping from 10 to 60°.
Smoky River Coals	McIntyre Mines Ltd.	Seams to 10.5 m thickness dipping from 20 to 55°.
Tent Mountain (Coleman)	Norcen Energy Resources	Seams to 9 m thickness dipping from 10 to 60°.
Sparwood (B.C.)	Westar Mining	Seams to 15 m thickness dipping 10 to 55°.
Greenhills (B.C.)	Westar Mining	Seams to 6 m thickness dipping 10 to 40°.

TABLE 3-2 (Cont'd)

Property	Owner	Mining Conditions
CATEGORY IVB (Cont'd)		
Line Creek Mine (B.C.)	Crowsnest Resources Ltd.	Seams to 9 m thickness dipping 10 to 50°.
Tulameen (B.C.)	Cyprus Anvil Mining	Seams to 18 m thickness dipping 10 to 30°.
Torrens (B.C.)	Cyprus Anvil Mining	Seams to 7.5 m thickness dipping 10 to 30°.
Saxon (B.C.)	Denison Mines	Multiple seams 3 to 10 m thick dipping 10 to 45°.
Gregg River Mines	Manalta	One seam 15 to 30 m thick dipping 10 to 60°.
Eagle Mountain (B.C.)	Fording Coal	Seams to 7.5 m thick dipping 10 to 30°.
Hosmer/Wheeler (B.C.)	Westar Mining	Seams to 7.5 m thickness dipping 10° to 20°.

3.4 PROPERTY DESCRIPTION

A brief description of the geology (stratigraphy, structure and reserves) is given below for each of the five selected properties.

341 RED DEER, ALBERTA

The Red Deer coalfield is located in the Plains region of central Alberta north and slightly east of the City of Calgary.

Stratigraphy

The nomenclature of the upper Cretaceous-Tertiary bedrock unit and associated seams was initially established by Allan and Sanderson (1945) which placed the Ardley seams in the Edmonton Formation somewhat below the massive sandstones of the Paskapoo Formation. The nomenclature and stratigraphic boundaries were modified to reflect that used today where the Ardley seams are located within the Scollard Formation of the Edmonton Group.

Two principal Ardley coal zones were recognized in the Red Deer area. The Lower Ardley A Zone which is relatively thin, often 1 m or less, and the overlying Lower Ardley B Zone which is considered the main resource of the area. The Lower B is further subdivided into the Lower Ardley Main B, Lower Ardley Sub B_2 and Lower Ardley Sub B_1.

The Paskapoo Formation consists of massive sandstones, claystones, siltstones and minor bentonitic horizons. The roof of the seams are usually comprised of the massive sandstones or a shale sequence overlain by massive Paskapoo sandstones. The seams vary little in thickness across the area. The Ardley Main B from 1.3 m to 2.3 m, the

Sub B_1 consists of 1 to 3 seams and the Sub B_2 usually contains 1 or 2 splits. The aggregate thickness may approach 3.5 m.

Stratigraphically lower in the Edmonton Group are the seams of the Horseshoe Canyon Formation. Two zones have been identified, the Lower Horseshoe Canyon and Carbon Thompson coals. These coals are not considered economically viable in the Red Deer area.

Structure

The structure of the Red Deer area is monotonously simple with the bedrock topography following closely the surface topography. The beds strike north south with an average dip of 3.8 m per km to the west. Depth to seam ranges from 100 m to 300 m.

Reserves

Reserves, as calculated by others, place the total reserve of the TransAlta Red Deer area, including the leasehold and also freehold at 3890 million tonnes.

342 DENISON QUINTETTE (BABCOCK MOUNTAIN, B.C.)

The Quintette coalfield is located in north-eastern B.C. and extends from near Chetwynd southeast towards the Alberta, British Columbia border.

Stratigraphy

The bedrock strata ranges in age from Upper Jurassic to Lower Cretaceous and the main coal seams are located in two distinct stratigraphic horizons: the Gates member of the Commotion Formation and the Gething Formation.

The Gates member is 262 to 290 m thick and divided into the lower portion which is made up of massive, light grey, medium grained sandstone with minor carbonaceous and conglomeritic horizons. The upper portion is the producing level being made up of fine to medium grained sandstone, carbonaceous and light grey shale, coarse sandstone lenses, and coal seams. The coal seams considered mineable are the D, F and J seams. The roof material of these seams is usually composed of shale or sandy shale to very fine grained sandstone and coal seams, D seam being the exception which is overlain by coarse conglomeritic sandstone or pebble conglomerate.

The Gething Formation is composed of fine to coarse grained sandstone, carbonaceous shale, coal, sandy shale, conglomeritic sandstone thickly bedded to massive. The Gething Formation features thin consistent seam development of two to four metres.

Structure

The coal measures at Quintette are located in broad synclines and sharper anticlines separated by medium to high angle thrust faults. The faults dip southwest and have vertical displacements of up to 100 m. The main underground reserves are located in large structurally continuous blocks on the flanks of synclines and anticlines, dipping at between 5° and 16° and ranging in depth from 100 m to 450 m.

Reserves

The underground reserves as calculated by others are:

Babcock Mine	163 Mt in place

The Babcock Reserve is contained in 3 mineable seams D, F and J which are located in a flat synclinal structure and contains dips of 5° to 16°.

The seam thicknesses average 2.86 m for D seam, 2.48 m for F seam and 5.45 m for J seam.

343 LUSCAR (STERCO) COAL VALLEY MINE, ALBERTA

Geology

The coal measures are concentrated within a 210 metre interval of the Paleocene section. The coal seams were originally named by the mining companies in the earliest days of development of the area and these names continue to be used today. Of the five main seams, only three are presently economic to mine based on quality, thickness and depth of cover. These are the Val D'Or, Upper Silkstone and Mynheer. The Coal Valley Mine is located in the structurally deformed foothills area of Alberta and the structure of each mining area is therefore very complex. The general bedding strike is 305 degrees azimuth but major thrust faulting and folding has extensively deformed the natural seams as a closer examination will show.

The Mynheer Seam, located at the base of the coal measures, ranges in thickness from 5 m to 10 m and has numerous bentonite and shale partings. Because of inherent geological features, the Mynheer Seam has been subdivided into two zones, the Mynheer 'A' and the Mynheer 'B', and the mining of coal in these zones has necessitated the utilization of distinctly different mining methods. The structural regime of the Mynheer 'A' Zone consists of an overturned assymetrical anticline crest containing a steeply dipping major thrust fault which has raised the seam above the present topographic level. Further extensive shearing and rotation of the coal has resulted in the coal taking a 'pod' shape.

The Mynheer 'B' Zone is a continuation to the southeast along strike from the Mynheer 'A' Zone. The bedding dips to the southwest at an average of 12 degrees and is interrupted at the south end by a transverse fault and to the north by its outcrop at the surface.

The Silkstone seam, in places split by 3.0 m to 6.0 m of sandstone and siltstone into the Upper and Lower seams, lies 43 m to 50 m above the Mynheer seam. The upper seam averages 3.5 m thick and this part of the seam is deemed economically mineable by underground methods. A small test mine has been under development.

The Val D'Or Seam has a total coal interval of up to 10 metres. It is characterized by up to six partings, the largest of which is sandstone and runs to 3.5 metres in thickness. The dip averages 12 degrees. Mining of this seam is complicated by the selective mining methods necessary to remove most of this parting material and also to contend with additional local faulting which occur to the south end of the mining area.

Coal Reserves and Quality

Proven reserves contained within the current mine permitted area are calculated to be 40 million clean tonnes capable of being mined by surface methods. In addition there are 30 million tonnes of proven underground mineable reserves.

Coal Valley Mine produces bituminous thermal coal with the following specifications:

Total Moisture	9.0%
Ash	8 - 10%
Volatile Matter	33%
Fixed Carbon	49%
Sulphur	0.3%
Calorific value	Gross 6,150 MJ/kg

344 WILLOW CREEK, B.C.

The Willow Creek coalfield is located in the Pine River Valley which is 50 km west of Chetwynd, British Columbia.

Stratigraphy

The property is underlain by rocks of Lower Cretaceous age of the Gething Formation which together with the Cadomin Formation make up the Bullhead Group. The strata consists of fine-grained, cherty to quartzose sandstone, rusty weathered shale, carbonaceous mudstone, coal seams and minor conglomerate. The conglomerate is called the Blue Sky conglomerate and indicates the boundary between the Bullhead Group and the overlying Fort St. John Group. The coal is divided into eight separate seams which vary in thickness from 2.0 to 4.2 m.

Structure

The Willow Creek property is located on a structure known as the Willow Creek anticlinorium. A small gentle fold occurs on the east limb of the much broader Willow Creek anticline. The synclinal axis is marked by a fault/shear zone which is visible in outcrop. The underground mineable section of the structure dips at 34° to 37°.

Reserves

Underground reserves were calculated in seams which were deemed to be amenable to underground mining and were calculated to 400 m depth and are as follows:

	Thickness (m)	Reserves ($t \times 10^6$)
Seam 1	3.0	5.26
Seam 3	2.5	2.79
Seam 4	3.6	6.24
Seam 6	4.2	2.08
Seam 7	2.4	11.87
TOTAL		28.24

345 DENISON - SAXON

The Saxon property is located in the Peace River coalfield of northeastern B.C. to the south and east of the Quintette property approximately 185 km east of Prince George.

Stratigraphy

The coal bearing sequence is located in the Commotion Formation which forms part of the Fort St. John Group being bounded by the underlying Moosebar Formation and overlain by the Shaftesbury Formation. The Commotion Formation is divided into three members, the Boulder Creek, the Hulcross and the Gates (in descending order).

The stratigraphic section with the greatest economic interest in the Saxon area is the Gates member.

This member is mainly a non-marine unit and consists of sandstone, conglomerate, coal, shale and mudstone and has an average thickness of 365 m. Contained within this thickness are six potentially economic coal seams with an aggregate thickness of 18 m. The seams are labelled 1 through 5 and No. 10. Three of these seams, 1, 2 and 4, are suitable for underground mining in the eastern portion of the property.

The seam thicknesses are 1.86 m, 1.98 m and 2.51 m minimum to 9.1 m, 14.38 m an 14.04 m respectively.

Seam No. 4 has an immediate roof (1-2 m) of shale and claystone with overlying siltstone and sandstone.

Seam No. 2 has an immediate roof of upward fining sandstone (massive) which grades in the south portion to pebble conglomerate.

Seam No. 1 has a sandstone roof grading upward to a siltstone.

All seams have a sandstone floor except seam number 2 where in the south the floor grades to conglomerate.

Structure

The structure of the Saxon property is dominated by a large synclinorium trending northwest and plunging north and south toward the centre. It is the eastern portion of this syncline which is attractive for underground mining. Large scale thrust faults dipping 50° to 70° are commonly encountered in the eastern section. But as the strata is dipping at 30° to 50° the angular relationships are in the area of 10° to 20°.

Reserves

The underground reserves in Saxon have been calculated for three areas: Saxon East, south of Narraway River and Saxon East, north of Narraway River and Saxon West. These reserves are (to a depth of 500 metres):

Area	Coal in Place $t \times 10^6$
Saxon East south of Narraway	190.3
Saxon East north of Narraway	70.5
Saxon West	26.4
TOTAL	287.2

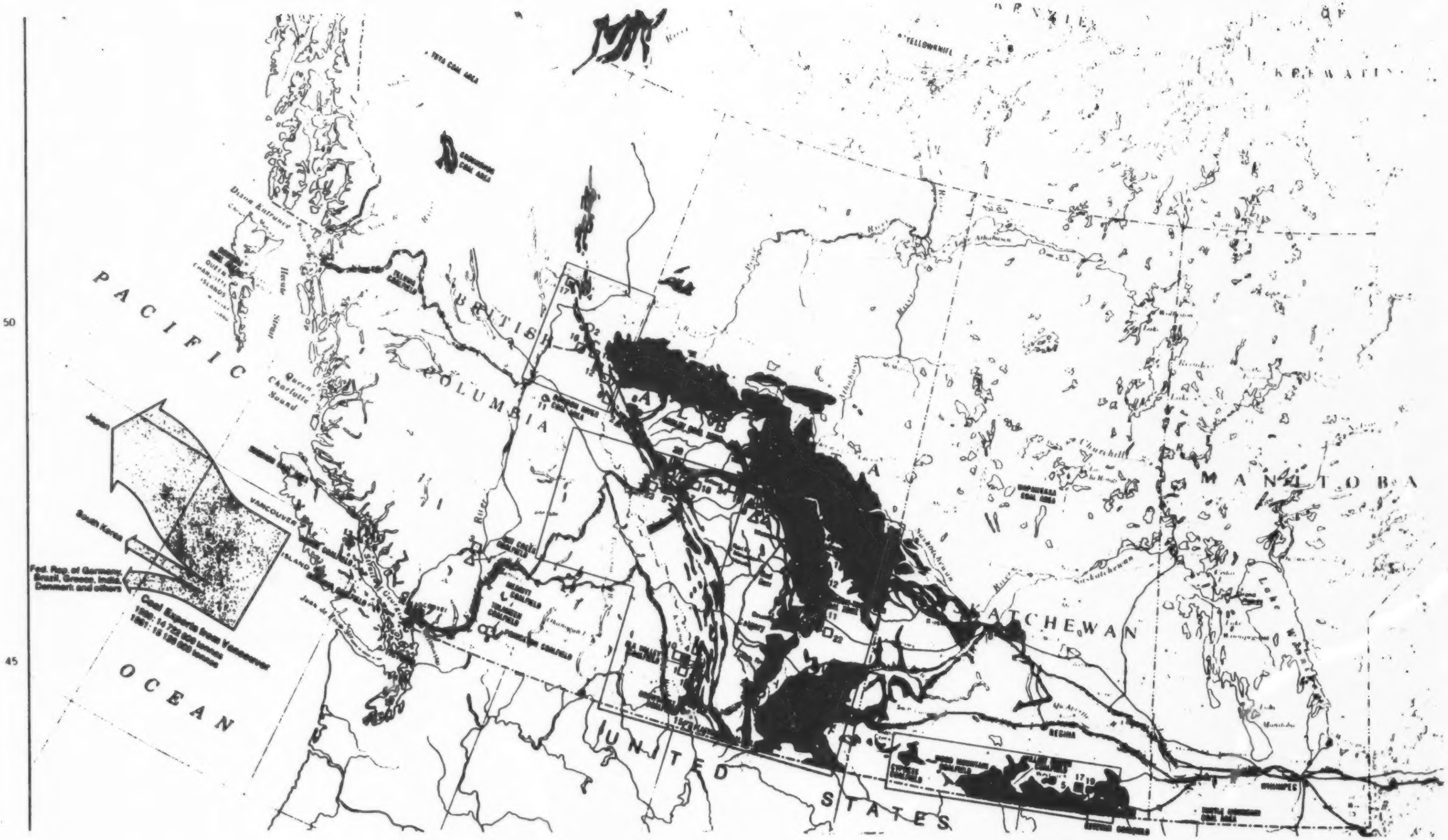
50
45
PACIFIC
OCEAN
BRITISH COLUMBIA
ALBERTA
SASKATCHEWAN
MANITOBA
KEEWATIN
UNITED STATES
YELLOWKNIFE
REGINA
WINNIPEG
VANCOUVER ISLAND
QUEEN CHARLOTTE ISLANDS
Dixon Entrance
Hecate Strait
Queen Charlotte Sound
Strait of Georgia
Juan de Fuca Str.
Churchill
Athabasca
Saskatchewan
Lake Winnipeg
South Korea
Fed. Rep. of Germany, Brazil, Greece, India, Denmark and others
Coal Exports from Vancouver

FIGURE 3-1 WESTERN CANADIAN COALFIELDS

(COURTESY ENERGY, MINES & RESOURCES CANADA)

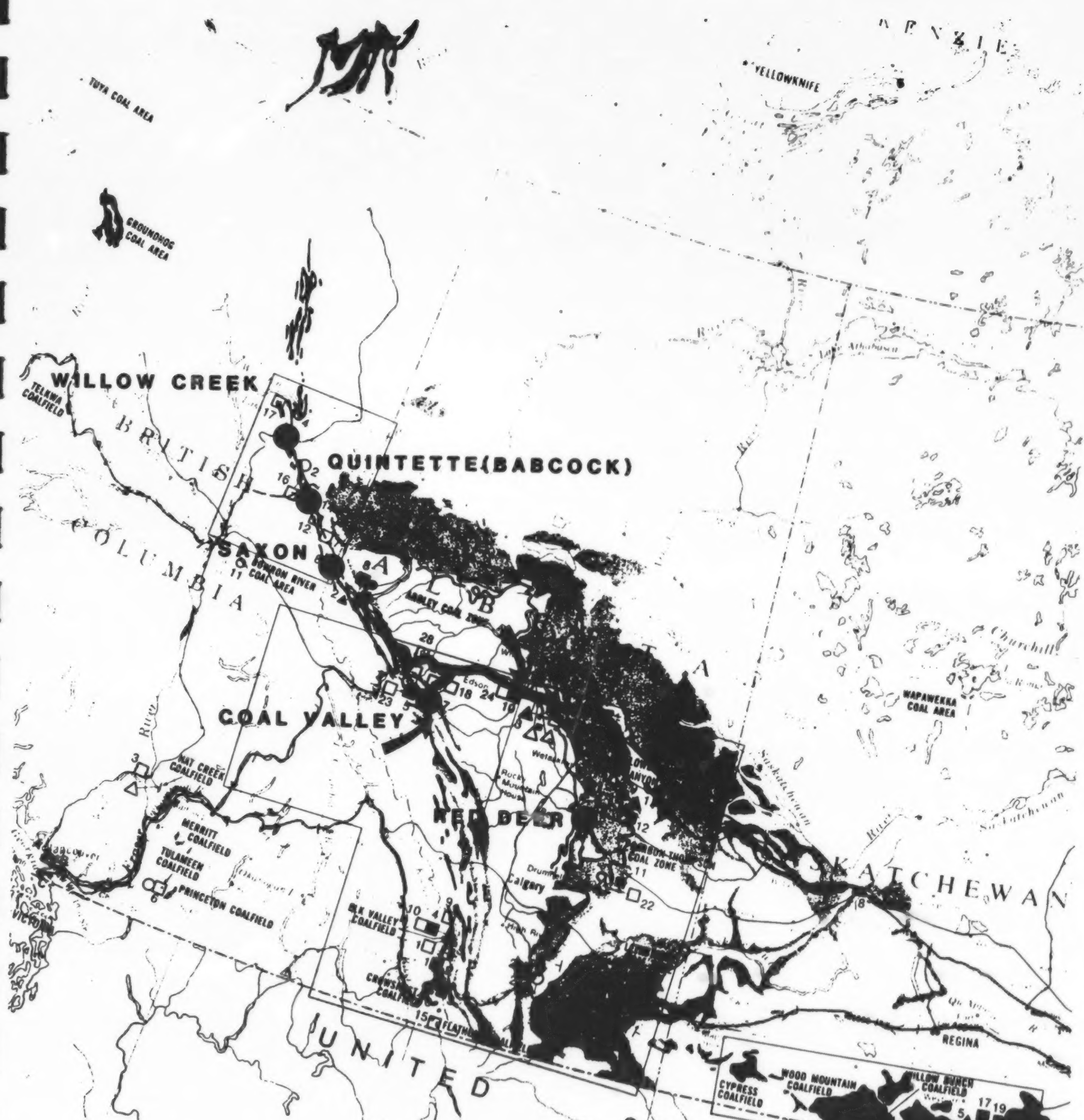
TUYA COAL AREA
YELLOWKNIFE
GROUNDHOG COAL AREA
WILLOW CREEK
TELKWA COALFIELD
BRITISH COLUMBIA
QUINTETTE(BABCOCK)
SAXON
ALBERTA
COAL VALLEY
Edson
RED DEER
Calgary
HAT CREEK COALFIELD
MERRITT COALFIELD
TULAMEEN COALFIELD
PRINCETON COALFIELD
ELK VALLEY COALFIELD
WAPAWEKKA COAL AREA
SASKATCHEWAN
REGINA
CYPRESS COALFIELD
WOOD MOUNTAIN COALFIELD
WILLOW BUNCH COALFIELD
ESTEVAN COALFIELD
UNITED STATES
VICTORIA
Lake Athabasca
Churchill

FIGURE 3-2 LOCATION OF SELECTED PROPERTIES

(COURTESY ENERGY,MINES & RESOURCES CANADA)

PART 4 - NEW AND DEVELOPING TECHNOLOGY

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4.1 INTRODUCTION

In the course of our search, we contacted more than 300 potential sources of information around the world. This did not identify any new and unconventional underground coal mining methods. The general comment made by most respondents was that there have not been any new mining methods or technology developed for many years and what is often called new technology is more often an extension or development of existing technology.

However, a number of variations on existing methods were identified. These are not presently in use in western Canada, but with further development or modification, some would have application in future underground coal mines in western Canada.

Insitu gasification was specifically excluded from the terms of reference of the study. The methods excluded include:

- Underground gasification
- Pyrolysis
- Complete combination
- Quenched combination
- Solvent digestion
- Aqueous phase liquefaction
- Supercritical gas extraction
- Chemical communication
- Microbiological degradation

4.2 RECENT DEVELOPMENTS

These can be divided into two categories, those which have been recently introduced and are working in operating mines, and those which have been postulated but either never tried or only for very short periods.

In the first category are:

1. Yielding Pillar Shortwall System
2. Rib Pillar Extraction System
3. ESA Shortwall System
4. Wongawilli System

In the second category are:

1. Underground Auger Mining
2. Narrow Hydraulic Room and Pillar Mining
3. Thin Seam Borehole Hydraulic Mining
4. Radial Mining
5. Remotely Controlled Mining

A brief description is given in the following sections of the basic principles of each method, including the major advantages and disadvantages of each method or development.

4.3 RECENTLY INTRODUCED SYSTEMS

431 SHORTWALL MINING - YIELDING PILLAR SYSTEMS

The most interesting and most recent change in mining methods is in the Carlsbad Potash basin in New Mexico, where two companies are using the shortwall system of mining to achieve very high extraction ratios without fracturing the roof strata. This involves the use of a system of yielding pillars.

A panel up to 305 m wide and up to 762 m long is formed by driving three or four 9.1 m or 11 m entries along the centreline. Pillars are square or diamond shaped being either 6 m wide by 21.3 m long or 9.1 m wide by 27.4 m long. Crosscuts are driven at 90° or 60° respectively (Figure 4-1).

When the limit of the panel is reached, mining commences on either side of the access entries. The ripperhead miner drives a 3 or 4 pass room (9 m or 15 m wide depending on the mine and the miner model) for 120-140 m, forming, on the inbye side a 2.4 m deep 3.1 or 3.8 m wide 60° crosscut, every 9 m. When the room is completed, a 1.8 or 2.4 m wide pillar is left and the next 9-15 m wide room commenced. The first pass of this room is alongside the pillar, and as it is mined, the 60° crosscuts are intersected, the pillar line thus becoming a series of small yielding pillars. These crosscuts assist with ventilation and dust control. As the panel is mined out on the retreat, the pillars of the central entries are also extracted. The ripperhead miners are served by shuttle cars delivering via feeder breakers onto the conveyor transportation system. Maximum one way hauls are limited to 200 metres.

In one mine, waste salt above the potash beds has to be mined to provide working head room. This salt is mined separately and dumped by the shuttle car in the previous mined out room, where it eventually assists with roof control (Figure 4-2).

The control of the roof in this 92% extraction mining system is excellent. The small pillars act as yielding pillars which severely deform and allow the roof to lower uniformly. Some areas can be seen which have been mined by this method three years previously, and convergence is between 0.8 m and 0.9 m of the original mined height of 1.4 m, with the roof strata still intact. However, experience has also shown that if the room width is increased by one further pass, considerable problems develop with roof stability and vastly increased rates of convergence occur as do minor roof falls. In normal circumstances, the convergence in these shortwall systems averages between 12 and 25 mm per day for the first 30 days and decreases thereafter. Surface subsidence over extended areas of shortwall working has reached 75% of the seam height extracted. No trouble has been experienced with the Rust aquifer which lies some 140 metres above the mining zone.

The main factors that have permitted the high extraction are the modest depth of the workings below surface, typically 300 m with a maximum depth of approximately 520 m and a thick evaporite sequence of approximately 140 m above the mining horizons providing an impermeable barrier between the workings and overlying aquifers.

At one of the mines, deformation measurements have been taken in both excavations and pillars during the mining of potash by the shortwall system with yielding pillars. More than 90% of the ore is extracted leaving approximately 8% in the form of a symmetrical array of small pillars which undergo severe deformations over relatively short periods of time. The measurements monitored large deformations all the way to failure. The following measurements were taken:

- Pillar deformation
- Roof and floor closure between the pillars and rows of pillars

- Separation of strata due to mine deformation
- Stress measurements in pillars

These measurements were centred on one of the small yielding pillars in the centre of each panel. The pillars are approximately 2.4 m x 6.1 m, 3.1 m apart with 18.3 metres between rows. The nearest boundary was between 45 and 60 metres away. A second pillar, 24.4 m long, was used in a second similar situation (Figure 4-3).

Typical results were:

A. Small Pillar (2.4 m x 6.1 m)

1. Roof-Floor Closure
   - 25 mm/day for first 30 days
   - slower thereafter
   - 2/3 from floor convergence, 1/3 from floor heave
   - closure uniform in room
   - closure at centre of room similar to that between pillars
   - face advance 20 metres per week

2. Pillar Extension
   - on width, elongations of 12 to 17 mm per day for 30 days
   - on length, elongations of 17 mm per day for 30 days
   - no change in the centre core (1/4) of the pillar

3. Floor & Roof Strata
   - no appreciable separation of roof or floor strata within 10 metres

4. General Data - after 30 days
floor lift = 200 mm
roof lowering = 560 mm
- pillar slabbing occurred on a continuous basis

B. Large Pillar (2.4 m x 18.3 m)

1. Roof-Floor Closure - 8 mm/day for 30 days
2. Pillar Extension - 6 mm/day for 30 days

The longer pillar thus offers stiffer control to the lowering of the roof, but of course lowers the extraction ratio.

The major advantages of this system are:

1. High recovery of mineral
2. Excellent control of roof strata
3. Roof integrity maintained
4. Safe working method
5. Use of rock bolting as support would reduce any bed separation and improve roof integrity

The major disadvantages are:

1. Room width critical
2. Extensive geotechnical investigation required
3. In coal, may be problem with goaf ventilation
4. In coal, some form of roof support-rock bolting would be required, which could reduce productivity

A specific data base search was undertaken to identify mines operating with yielding pillars in sedimentary mineral deposits. Whilst there has been a considerable amount of research undertaken on the subject, only six underground mines were identified that are using the yielding pillar techniques. These are:

- Amax Chemical Corporation - New Mexico - Potash
- Mississipi Chemical Corporation - New Mexico - Potash
- Cargill Incorporated - New York - Rock Salt
- Byeloruskali - Soligorsk U.S.S.R. - Potash
- Uralkali - Berezniki U.S.S.R. - Potash
- Uralkali - Solikamsk U.S.S.R. - Potash

432 RIB PILLAR EXTRACTION SYSTEM

Rib pillar extraction is a generic name coined in South Africa to describe those methods that are based on extracting a rib of coal between the goaf and the development roads and which rely on a solid block of coal to provide the major support in the workings.

The method of extraction itself is a relatively new departure in the South African coal mining industry and it appears to hold great promise for the future and should make a significant contribution towards the increased underground extraction of coal in that country.

The method was introduced first at Sigma and Kriel Collieries in South Africa. Investigations at Sigma Colliery into optimizing continuous miner productivity and improving the percentage extraction in non-longwall sections led to the evaluation of the Australian Wongawilli and Munmorrah systems. After visiting Australia, mining personnel from the mine developed the rib pillar extraction method.

Mining Method

Primary development consists of three roadways driven to the end of the panel. The lengths of these roads are limited only by the type of conveyor belt installation used (Figures 4-4 and 4-5). The secondary development consists of two roadways driven at right angles to the primary development up to the boundary of the panel. Overlying this panel, there is a dolerite sill. Experience in the Sigma longwalls has shown that a panel width of at least 180 m is required in order to induce caving. Figure 4-5 illustrates the support pattern used during the development of the primary and secondary roads. Two roadways of 6 m width by 28 m length are then cut at right angles to the secondary developments so that a 7 m rib is formed between them. The 7 m width allows the continuous miner to remove the rib without exposing the operator to unsupported roof. Figure 4-6 illustrates the sequence of rib removal. The process is then repeated in sequence from 1-26. The rib between the two secondary roads is removed in a similar way.

The conveyor and travelling roads are used as intake airways and the third road serves as a return. The secondary roads and the working faces are ventilated with the aid of two auxiliary fans through spirally reinforced 760 mm ventilation tubing. The fans are so placed that the air is exhausted into the return airway. The 'bleeder' road on the opposite side of the goaf prevents the accumulation of gases in the goaf area.

Timber reclamation with wire rope slings was attempted but with little success because the timber generally broke when efforts were made to withdraw it.

Production Equipment

- 1 Continuous miner
- 2 Shuttlecars
- 1 Roofbolting machine
- 2 Auxiliary fans
- 1 Feederbreaker

Personnel (per shift)

Supervision: (Whites)

o	1	Shift Boss
o	1	Team leader
o	1	Miner
o	1	Fitter/Electrician
	4	

Operators and labourers: (Blacks)

o	1	Continuous miner operator
o	1	Cable handler
o	2	Shuttle car drivers
o	2	Rockbolts
o	4	Timber helpers
o	1	Feeder attendant
o	2 1/3	Maintenance operators*
o	1/3	Lubrication attendant*
	13 2/3	
Total	17 2/3	

* Shared with other units.

Production Rates

Working three eight hour shifts per day, production rates of up to 900 tonnes per shift are achieved in development drivage, and over 1200 tonnes per shift in rib pillar mining.

Percentage Extraction

An average extraction of over 95 percent (in panel), at depths between 90 m and 160 m, is obtained if proper sequencing is maintained. This in-panel percentage extraction could be obtained over an entire area as barrier pillars could also be extracted in the same way. This extraction is similar to that obtained with longwall operations at Sigma.

Rock Mechanics Aspects of Rib Pillar Extraction

The rock mechanics principles that have been developed for longwall mining can be used for the design of panel dimensions in this method of pillar extraction. The major difference between rib pillar extraction and longwall and shortwall mining is that, in the latter methods, work takes place under the goaf whereas in the former, work takes place under solid ground.

The lift driven across the panel creates a substantial rib pillar against the goaf. This rib pillar serves as a production pillar and is taken out in a systematic manner, retreaing towards the entry roads.

Controlled caving takes place when breaker lines and timber supports are drawn and any remaining snooks or small pillar remnants blasted. Because the method develops only one pillar at a time, which is then extracted, pillar run is not possible. Problems specific to rib pillar extraction result from the fact that coal mining takes place in an environment of increasing stresses at the face, caused by the progressive reduction over a short period of the area of the production pillar.

Delays during the rib pillar removal operation have been found to be detrimental to the stability of roof and pillar, and once work has commenced on the removal of a particular pillar, it is important that it be completed regardless of shift time. General policy was to try and ensure that the rib pillar would be removed during the seventeen shift working week and particularly before the weekend break.

The panel width has to be designed taking into account the thickness and caving characteristics of the rock strata overlying the coal seam. The overburden preferably should be impermeable to water and gases after reconsolidation. The local roof strata must safely 'bridge' the road and the increasing diagonal working span without failing. Together with the upper strata, they must allow early regular caving to minimize cantilever effects. The upper strata must cave at a steep angle to surface, instead of bridging the goaf or developing excessive overhangs.

Work carried out in Australia into rock stresses experienced with rib pillar extraction indicates that the distance from the goaf of the roads parallel to the goaf line is critical. The area of maximum stress will vary for different seams, depths and roof and floor strata types, and it is essential during the panel design stage to take these factors into account, in order that roads are not developed through this area of maximum stress. Figure 4-7 illustrates a typical example of such a stress distribution.

Costs

At Sigma, the operating costs of rib pillar mining were found to be 1.2 times that of conventional mining. This higher cost was due mainly to:

1. the high repair and maintenance costs of the continuous miner, and its low availability (60%),
2. the intensive roof bolting that was necessary in the geologically disturbed No. 3 seam.

Safety

If the correct mining sequence is strictly adhered, uncontrolled roof falls can be virtually eliminated. Correct operating and supervisory training is most important and the selection of people with sound mining experience is essential.

When rib pillar extraction takes place under a competent roof, allowing ventilation to bleed through the goaf area, it reduces the danger caused by methane and other gas accumulations.

The greatly reduced use of explosives minimizes the possibility of blasting accidents.

The area being mined at any time is small, consequently supervision is concentrated. The use of continuous miners furthermore minimizes the number of people required in the working area.

Developments currently taking place with this method include:

1. The use of crawler mounted powered shield supports for use in breaking off lines instead of the timber supports currently being used. The timber support is often inadequate and installation delays cutting. The first set of supports are now in use at Middelbult Colliery where they are expected improve productivity by at least 10%.

2. In order to minimize mine infrastructure and reduce the amount of development (less productive), mines are now trying a system using panels either side of the initial three entry roads and working a double header continuous miner system. These are seen as potential alternatives to longwall faces. This is being tried at Bosjesspruit Colliery.

3. The use of continuous haulage systems is being tried behind the continuous miner at Middelbult Colliery. A 142 m long Serpentix monorail mounted conveyor has recently been introduced and is expected to improve production by some 15%.

4. Trials with an Alpine AM100 miner mining a six metre seam in one lift with the rib pillar extraction system have just

commenced at New Denmark Colliery. This will be the first use of a Roadheader type machine as a coal production unit in South Africa.

Advantages

The major advantages of the Rib Pillar Extraction System are:

1. Enables high production rates to be achieved with continuous miner equpment and at a lower capital cost than longwall systems.
2. High extraction ratios are safely achievable.
3. The system is more flexible than a longwall system.
4. The system can be applied to geologically disturbed areas.
5. Coal production is concentrated hence supervision can be more effective.
6. Coal extraction takes place in a stress relieved area.

The major disadvantages are:

1. Extraction of the rib pillar is very time dependent. It must be completed in a continuous manner.
2. Requires a good understanding of the geotechnical behaviour of the roof strata.
3. Requires roof strata which is cavable.

433 ESA SHORTWALL SYSTEM

A new mining system has been developed by taking the principles used in mechanical cutting, conveying and roof support characteristic of longwall mining, and applying them to utilize the same equipment to drive the development roadways, open up a face line and mine out the coal pillar or block thus formed.

The ESA system has been developed jointly by Atlas Copco and Eickhoff.

The ESA mechanical cutting machine has been developed as a stablehole and face opening unit to mechanize these areas of longwall mining. The design is based on the proven shearer-loader principle and therefore represents a logical step forward in technological development. In the past, ESA units have mined stableholes and face openings, which in principle are similar to the rectangular layout of roadways in room and pillar. Converted to a 'road cutter', the ESA is successfully used today in driving arched or rectangular roadways.

The basic machine comprises a comparatively small body with attached ranging arm and cutting drum. The arm can move around the roof and floor, slewing through 360° (Figure 4-8). In standard form, the cutting height is defined by the drum diameter plus twice the length of the arm, giving a wide range (see Table 4-1).

Starting from a minimum roadway width of 4.5 metres, the extension of the conveyor pans and furnishings by 0.5, 1.0 or the standard 1.5 metres, allows for the adjustment of the unit to any width. To follow an uneven floor, the necessary control is provided by tilting cylinders and undercutting of the floor by the drum.

A single chain conveyor along the face and curving away perpendicular to the face moves broken material along and away from the face and feeds onto the panel conveyor transport system. The cutter rides on the armoured chain conveyor traversing the face and is guided by a roll bar. The conveyor is advanced alternately at each end, thus causing the ESA cutter to take wedge shaped cuts on the face. This eliminates the need for the cutter to sump directly into the face.

Roadway Development

In roadway drivage, performance depends on the successful selection and coordination of all the system components. The road cutter is therefore used with equipment that, to a great extent, overcomes the problems of setting roof support without interrupting the roadway advance.

The system comprises: a road cutter; two parallel, self-advancing chock supports; two rams connecting the cutter and chocks; roof bolting drills mounted on the chocks; a power pack for the cutter, chocks and drills; and a feeder breaker behind the machine conveyor [Figure 4-9(a)]. The self-advancing chocks, when jacked against the roof, provide an abutment for the rams to push the conveyor over and the cutter against the face.

While the cutter advances into the face in steps equal to the depth of the web of the drum, roof support remains at the same place until the effective extension length of the rams is utilized, usually about 1.5 metres. Simultaneously during this period, drilling and setting of roof bolts can be performed. Production and roof support can thus be carried out without interfering with each other.

When the rams are fully extended, the chock supports individually travel forward by pulling towards the cutter using the rams. The shields provide a safe roof at all times for the operators, which is particularly important during bolt drilling and setting.

The power requirement is fairly low, with an installed capacity of some 60 kilowatts for the cutter and an additional 100 kilowatts for the power pack. This supply provides for two supports and three drill units.

Assuming that the system can in reality only cut for 50 percent of the effective shift time, an output of 350 to 400 tonnes per shift, equivalent to an advance of 15 metres in normal roadway cross sections, can be expected. This is assuming that good transport is provided behind the system using an extendable bridge and belt conveyor system [Figure 4-9(b)].

Depending on roof conditions, rockbolting can be carried out behind the chock supports, or between cutter and support. The number of bolts required determines the number of drill units to be mounted on the supports. Ideally, the drills should serve one bolthole each, allowing the setting of one row of resin or friction bolts in approximately 3 to 5 minutes.

As an alternative to one drill per hole, one drill could be mounted on each support and travel along a horizontal beam to service each hole location. Usually rotary drills would be used. But for hard rock roofs, percussive drills could be utilized in order to maintain high operating rates.

With extremely poor roof conditions, where rigid or yielding arch supports are needed, a working platform is mounted on the cutter. An integral part of the platform is a hydraulic anchor beam with abutment jacks. This, when jacked into the walls, forms the abutment against which the rams can push to advance the system (Figure 4-10).

The platform is equipped with two horizontal bars on which two arches each are prepared to be set into the roof by a hydraulic arch setting boom. The boom lifts one or two arches at a time and sets them into the roof as close as possible behind the cutter. The boom travels back and forth between the two bars on the working platform. In this way, working areas close to the face are protected first.

A short interruption to the development drivage is, however, necessary when setting legs under the arches. Spacers between the arches and mesh screens are attached to the arches when they are resting on the working platform, prior to being set by the boom. Preparation of the arches, while cutting continues, reduces the time to finalize arch setting. If conditions permit, wire mesh screens can be attached to the arches as the cutter advances again.

Pillar Development

Room and pillar operations normally mean that each cutting system operates on two or three faces, since considerable time is lost in cycling the cutting, loading out, and bolt setting as the machines follow each other from face to face. The ESA road cutter system offers better utilization of shift time, manpower, installed power and capital.

The number of crosscuts should be kept to a minimum as these always constitute a hindrance to the main advance. An example based on a double entry block illustrates the method, cycle and application of the equipment (Figure 4-11).

To make use of time usually wasted in tramming and waiting, it is a prerequisite to keep the cutting and roof bolting system at the face. Bolting must be carried out as close behind the advancing face as possible without interfering with the cutter. Operators for cutting and bolting work in safety under the chock supports, behind the cutting drum.

The most likely applications in development are either to drive a single heading, form the face line and mine back the pillar thus formed, operating under single entry conditions, or to drive a double entry system, using two machines. In this latter case, twin entries can be driven as per Figure 4-11 with one machine and powered support system being used to mine back the pillar. Alternatively, with a single entry one machine can be mining back the pillar whilst the second machine is developing the conveyor roadway for the next pillar (Figure 4-12).

A mining crew should consist of four miners and a backup crew of three miners for ancillary work behind the bridge conveyor. This gives a productivity of approximately 70 tonnes per manshift.

One cutter system requires an investment of about $400,000; therefore, a double entry system would cost $800,000. However, the system will almost double production, and its labor costs are lower than today's most common methods. The electrical energy requirements are low with less than 200 kilowatts installed, covering the complete system including a bridge conveyor.

To avoid interruption of the main drivage advance, crosscuts can be driven by small-scale equipment. Machines such as cutter loaders are most suitable because of their size and application as multipurpose units.

Pillar Mining

In geological conditions that allow pillar recovery, the layout of the panel can be arranged to give a high recovery. As the cutter can operate on faces longer than 4.5 metres it can also be used for pillar recovery. Except for turning round the conveyor to retreat back and replacing the chock supports by a self-advancing shield system, all components remain the same (Figure 4-12). Utilizing the comparatively low installed power, a pillar length up to 30 metres is regarded as economical. This allows for an advance rate of at least 5 metres per shift, equivalent to approximately 500 tonnes per shift, in a seam height of 2.5 metres in coal of average hardness. Capital investment costs remain fairly low and allow for an acceptable return.

Setting of wooden safety props can be eliminated because of the shield support, which provides adequate operator safety. A bridge conveyor, between the chain conveor and the main belt, rides on the frame of the panel belt conveyor which retreats automatically. With an assumed advance of 5 metres per shift and two shifts per day, the bridge conveyor should be 20 to 30 metres long to allow for shortening of the main belt conveyor during the night shift every second or third day. The belt size used during roadway drivage should match the requirements of pillar recovery, which has the highest production potential.

A main belt conveyor, with bunker storage installed at the main gate, provides both the advancing development and pillar recovery systems with a coal transport system of utmost flexibility. Parallel entries to the conveyor roadway feed their production through crosscuts onto the main conveyor.

The major advantages of the system are:

1. Can deal with geologically disturbed areas and can mine isolated areas of coal.

2. Same equipment used for development and pillar recovery.

3. Low capital cost.

4. Early and effective support provided in headings and full support by shields during pillar recovery.

5. High mining recoveries possible.

6. High productivities possible.

7. Very safe mining system.

The major disadvantages are:

1. Requires additional equipment to excavate cross-cuts.
2. Cutting equipment not mobile like continuous miner and roadheaders, thus limiting machine flexibility and requiring dismantling and transportation between working places.
3. Requires cavable roof for application of high extraction methods, but can be readily applied to partial extraction.

434 WONGAWILLI SYSTEM

In Australia, permission for the mechanical extraction of pillars was gazetted only in the early 1950's. Continuous miners were used first for pillar extraction in the mid-fifties. These machines eliminated the disadvantages of conventional equipment and the necessity for multiple working places. Some innovations in panel layouts emerged but actual pillar extraction methods still followed closely those of hand loading.

In the early 1960's, pillar extraction was carried out using the 'open end lift' or 'split and lift' methods. These methods did not give the percentage extraction required because operators were sometimes unable to complete lifts in the 'open end lift' system or to completely remove the snooks in the 'split and lift' system. This caused deterioration in the mining conditions and also affected adjacent areas, the result being that recovery decreased as the panel retreated.

The Wongawilli method was then developed and the objectives were:

1. to provide a single working place,
2. to extract coal in a 'stress relieved' area,
3. to utilize the coal fenders as temporary support during extraction operations,
4. to achieve up to 90 percent extraction by area.

The Wongawilli system, in effect, is a shortwall face in which the powered supports have been replaced by a fender of coal, which is subsequently 'pocketed' on retreat.

Mining Method

The application of the Wongawilli method varies from colliery to colliery, being dependent on prevailing conditions; for example, depth of seam and the properties of the rock strata overlying the coal seam. The method described here is used at the Nebo Colliery, New South Wales, Australia. Figure 4-13 illustrates the panel layout and the development sequence. In this particular colliery, all development roadways are supported with 'reject' 44 kg rails, 1.2 m apart, but various support sytems are used at other collieries employing the Wongawilli method.

When the drives have reached the end of the panel, splits are systematically driven to the barrier (L22, L23, etc.). The rib between L22 and the goaf line is subsequently pocketed on the retreat, the snooks or small pillars so left finally being crushed by the goaf. When lift and rib L22 have been extracted, work commences on L23. The pillars between the three entry roads are also pocketed as the panel retreats.

The major problems in working this system are:

1. when trouble caused by poor roof conditions is encountered and operators are unable to complete a lift, large snooks are formed, which cause weight to be transferred to the development roads, resulting in deteriorating mining conditions,

2. the single roadway can create ventilation problems if the goaf seals off the ventilation. An added danger of ventilating through the goaf is the possibility of creating conditions conducive to spontaneous combustion. Many mines using the Wongawilli method carry an exhaust ventilation duct just behind the continuous miner and do not exhaust over the goaf.

The average panel width is 110 m and the 'rib' is 7 m, which allows the continuous miner operator to be under supported roof at all times.

Production Equipment

- 1 Continuous miner,
- 2 Shuttlecars,
- 1 Feederbreaker,
- 2 Roofbolting machines (if bolts are used).

Personnel

- 1 Section Foreman,
- 1 Continuous miner operator,
- 2 Shuttlecar operators,
- 2 General labourers for support, ventilation, etc.,
- 1 Mechanic.

  7 Total

Production Rates

Production rates average about 500 tons per shift and operations normally have three production shifts of 6 hours each and a 6 hour maintance schedule.

Extraction rates (in panel) of over 90 percent have been achieved under good mining conditions, but the average is slightly less.

Thick Seam Extraction

The Wongawilli system can also be used to mine thick seams. In Australia, where the system is primarily used, an arbitrary maximum seam thickness has been determined to be that which can be safely and efficiently mined in a single lift by a continuous miner. As the normal continuous miner can mine up to a maximum of 3.5 m, in Australia the term thick seam is generally accepted to mean seams that are greater than 3.5 m in thickness.

Because a large percentage (at least 50%) of the coal in thick coal seams was not being recovered, research into ways to improve the situation was started in the 1970's. Since the majority of mining equipment available and in use in Australia at that time consisted of continuous miners and shuttle cars, preference was given to systems that would continue their use. Similarly as the Wongawilli mining system was also widely accepted and extremely successful in less thick coal seams it was considered the natural system to use to develop the thick seam extraction technology around.

It was decided to recover the coal in two lifts, first the top section of coal and then the lower section of coal, somewhat along the lines that had been successfully applied in some countries using the longwall mining method. Because seam and strata strength, depths of cover and many other factors could seriously affect the results of field trials of the concept, considerable laboratory research and testing was carried out before a design was finally established that would offer greatly increased coal recovery in a safe and efficient manner. The resultant system is a double lift, potentially 100% extraction system that uses existing, readily available equipment and materials.

The following briefly lists the various segments of the system as designed to recover an approximately 6.0 m thick coal seam:

1. Develop the upper 2.0 m of the seam using a typical Wongawilli layout (Figure 4-14).

2. In the coal floor in all development roadways and places driven to form fenders install 2.0 m long wooden dowels cemented in place by resin grout in a 1.0 to 1.5 m pattern. These dowels will reinforce the interlayer of coal between this and the lower 2.0 m extraction slice and, as they are wood, they will not damage or hinder the cutting of the lower coal by the continuous miner.

3. Extract the upper 2.0 m of the seam as completely as possible. Due to the height of 2.0 m coal recoveries in the range of 95 to 99% are said to be achievable.

4. Develop the lower 2.0 m of the seam, leaving a 2.0 m layer of intercoal as a roof between the upper and lower areas. See Figure 4-13. As seam thickness often vary the bottom end of the wooden dowels can be used as a guide and to prevent inadvertent reduction of the inter coal layer to an unworkable thickness. In laying out these lower workings care is taken to ensure that they are exactly below the upper ones.

5. Complete the extraction cycle using a typical Wongawilli system but in addition as the continuous miner retreats it cuts as much of the layer of coal between the lower and upper workings. Naturally a continuous miner with a reach of 4.0 m is required to achieve this.

The advantages and disadvantages of the Wongawilli system are identical to those stated for the rib pillar extraction, with one exception. Difficulty was often experienced in extracting the last sections of the pillar, because it usually took longer than a week to mine and had to stand at the weekend. Deterioration in roof and stress conditions resulted. This was the main reason why the Rib Pillar system of the South Africans operated with shorter pillar lengths.

The major differences between the South African Rib Pillar method and the Australian Wongawilli method are:

- The rib pillars are considerably longer in the Wongawilli method (110 m vs 24 to 48 m). This is why more coal is lost in unrecovered sections of the rib pillar because it is often too long to mine in one continuous working period.

- The Wongawilli method uses a three entry secondary development, compared with the two entry of the Rib Pillar method. This results in a higher proportion of development coal than depillaring coal with the Wongawilli system, and thus, overall, slightly lower productivities and production.

- Ventilation in the Wongawilli method is through the goaf, whereas with the Rib Pillar method, ventilation roadways equipped with auxiliary fans are provided around the edge of the goaf to also act as gas bleeders.

- The Rib Pillar method makes extensive use of mobile and cross conveyor belts to either eliminate shuttle cars or keep their travelling distance to an absolute minimum.

4.4 CONCEPTUAL OR LITTLE USED SYSTEMS

441 UNDERGROUND AUGER MINING

Auger mining is not a new concept with respect to surface coal mining and under certain conditions is very successful. It has not however been so successfully used in underground mines.

Some of the earliest underground coal mine auger use was reported to have taken place in 1958 when USBM engineers tested it to drive inseam ventilation connections between parallel underground roadways. Production rates were poor and further development did not proceed for many years. In the 1970's renewed interest brought about the development of more powerful and modern machines of differing size and shape to recover thin coal seams, seams with poor roof conditions or to recover sections of coal from seams that have major dirt bands in them without excavating the dirt band.

Although auger mining in underground coal mines has not been developed to any great level and it has not proved to be a popular method within the coal mining industry, three distinct variations of auger mining have been proposed and to some degree tested and utilized. These are Panel Mining, Pillar Recovery and Variable Longwall Auger Mining:

Panel Mining.

In this variation an underground coal auger (Figure 4-15) is used to mine panels of coal that have been blocked out using conventional mining techniques. The blocks can be several hundred metres long and between 25 and 100 m wide. The auger is positioned at one end and to the side of the pillar and proceeds to mine the pillar by augering large diameter holes all the way through the pillar. These holes could be 1.0 to 2.0 m in diameter. Unfortunately control of the horizon of the auger in the coal seam is difficult and it quite often strikes the roof or floor rock with resultant increases in ash in the product and high rates of wear on the auger itself. It is possible that a steering and control system can be developed to overcome this problem in the future, however lower than planned production rates to date are not likely to encourage coal operators to pursue this system too strongly.

Pillar Recovery

When used to recover coal pillars as part of a normal room and pillar or even longwall operation as an area is retreated, the auger is less affected by the problems of directional control. In theory the system should be more attractive however, to date we understand there has been little significant use of this variation of augering.

Longwall

A different and novel conceptual way to combine the basic principles of the auger in a longwall mining system has been proposed by L.T. White. This system is essentially a series of side cutting augers connected together by universal joints to allow the transmission of rotary power along the series of augers while at the same time allowing them to pivot in any direction to a limited degree. To produce coal on the 'longwall' the augers are rotated and at the same time pushed into the coal face starting at one end or one end and the centre of the face and continuing along the face in a 'ripple' motion so cutting the coal with the side of the auger and loading the coal along the auger spiral (Figure 4-16). To accommodate seams thicker than the auger dimensions the auger is raised and lowered by a series of hydraulic raims or jacks (Figure 4-17).

The USDOE and Undata Associated Inc. (USA) have both analyzed the concept and feel that it could be developed to be a successful system. The system has not been developed and tested in an underground coal mine to date.

The advantages of auger mining are:

1. Can be applied to small areas of coal.
2. Can be applied to thin seams.

The main disadvantages are:

1. Poor directional control.
2. Limited to partial extraction of the seam.
3. Limited length of advance.
4. Squeezing ground presents severe difficulties.

442 NARROW EXCAVATION HYDRAULIC ROOM AND PILLAR MINING

In the underground coal mines of the Soviet Union research into mining techniques that can be very productive, safe and efficient has covered many fields and in some cases brought forth very rational and meaningful variations to existing mining methods. One such variation has been pursued to the extent that it is said to be the safest and most productive system in use in the Soviet Union today and at the same time uses less roof support material than any other system. To achieve this somewhat remarkable situation, Soviet engineers have reevaluated precisely what underground coal mining is and identified the major problems with the present conventional systems. They are:

1. Underground coal mine roadways are usually large, take considerable time to develop and require costly materials for their support.

2. Coal production is usually sporadic for many reasons.

3. During production or transportation, coal is often 'dirtied' by inclusion of out of seam dilution.

4. Coal transportation is seldom 100% reliable causing delays in coal production.

5. Coal production and transportation usually generate high levels of coal dust which travels in the mine ventilation air.

The Soviet solution to these common problems was to start the whole process of mining from the beginning. The following are some of their published considerations:

1. In any underground mine the size of the roadway opening can be self-supporting, e.g. in very strong roof strata such as strong sandstone, the excavated opening can be well over 6 or 7 m before roof caving problems occur, while in seams with fairly weak mudstones or shales, an excavation of only 4 to 5 m is sufficient to cause major roof falls unless supports are used to augment the natural roof strength. The concept they decided to pursue was to determine the optimum excavation size for roadways without roof support and, except in specific cases where wider roadways were essential, they designed a whole mine including extraction areas so that very little roof support would be required.

2. To minimize out of seam dilution they limited roadway height to the seam thickness (they have successfully mined down to 1.0 m seam thickness).

3. Possibly because the group involved in this project were part of the Soviet hydro mining research team, the transportation mode chosen was gravity assisted coal/water slurry (which can only be effectively used where seam gradients are favourable).

With this basic list of objectives, at least two known underground coal mines have been constructed and are successfully producing coal. One mine, the Yubilania Mine in the Kusbaz Coal Basin of Siberia, is said to be using the above concepts to recover coal from several coal seams that have thicknesses from 2.0 to 3.5 m and gradients of approximately 20 degrees. Reports from this mine state that it is the safest and most productive mine in the USSR.

The system developed was essentially a variation of a typical room and pillar system with roadway widths not exceeding 3.0 to 3.5 m in most areas, as this was the ideal safe self-supporting excavation width in their conditions (Figure 4-18). To enable these narrow roadways to be driven, a very small low production continuous miner was developed (Figure 4-19), and although this machine can only mine some 2.5 tonnes per minute, it has produced approximately 900 tonnes per eight hour shift during pillar recovery and 500 to 550 tonnes per eight hour shift during panel development, because it does not have to stop to install roof supports or extend the hydraulic coal transportation system.

Limitations to the use of the system are primarily those controlled by the gravity coal-water coal transportation and the maximum gradient on which the machine can operate.

The major advantages of this system are:

1. Little or no support is required.
2. Reduction in material supply requirements.
3. Increased machine availability and hence greater production and productivity.
4. With the hydraulic transport, dust and methane release are reduced.
5. Could be applied with conventional transportation systems.

The major disadvantages are:

1. Limited by gradients for either flume transport or machine manoeuvrability.
2. Requires small cutting machines and backup equipment.
3. Requires an excellent knowledge and appreciation of the behavioural characteristics of the roof strata.

443 HYDRAULIC BOREHOLE MINING

.1 Steep Thin Seam (Borehole) Hydraulic Mining

The development of safe and economical recovery of coal contained in thin coal beds or seams that have significant gradients has been pursued for many years in many countries. One interesting, technically successful, but at present uneconomic system is the hydraulic mining system developed largely in the USSR and West Germany - borehole hydraulic mining. No personnel are required in the actual coal production area so it can be classed as a semi automatic or more properly remotely controlled system.

Underground borehole mining is usually practised in very steep and relatively thin, 0.5 to 4.0 m thick, coal seams. To utilize this technology a basic network of major roadways and suitably sized extraction pillars is developed by driving parallel inseam roadways approximately 100 m apart (Figure 4-20). Hydraulic mining, using a gravity powered coal-water slurry transportation system from the face or production area to the main roadways, requires panel roadways driven at gradients between 3 and 7 degrees. After completing the development phase, a specially constructed hydraulic water jet drill is used to bore a pilot hole from the lower roadway to the upper roadway. This hole is usually between 100 and 450 mm in diameter. After completing the hole, the hydraulic cutting elements are changed to specially designed coal cutting nozzles. By retreating the drill 'string' and its hydraulic cutting elements down the hole, the coal on both sides of the hole is mined and washed down the borehole by gravity to the lower roadway for subsequent transportation out of the mine.

After complete extraction of the 'cut', the equipment is moved between 5 to 15 m outbye towards the main entries and the whole process repeated. Continual repetition of this procedure enables a high percentage of the coal in the panel to be safely recovered. In differing seam conditions it may be necessary to make some variations to the above process, such as leaving coal pillars between the excavated strips or, where the flow of coal through the 100 to 450 mm hole cannot be maintained, by reversing the mining direction. In this latter case, the extraction part of the process is initiated at the lower end of the block to be mined and by retreating upwards with the hydraulic cutting elements, the coal that is mined can fall directly into the lower roadway without any risk of problems caused by blockage of the borehole (Figure 4-21). In West Germany the use of these methods enabled coal recoveries in the region of 70 to 75% to be achieved in conditions where the roof and floor rock were sound. In less favourable conditions poor recovery and out of seam dilution problems can make the system uneconomic. Similar methods to these used in West Germany have been used in several coal mines in the USSR with comparable results.

.2 Thick Seam Hydraulic Borehole Mining

Recent research work on the application of borehole mining by hydraulic means has shown that the system has potential for the mining of thick and steeply dipping seams down to depths of 400 metres.

The 'cavity' mining system (Figure 4-22) consists of a borehole (0.5 m diameter) drilled from the surface to the coal seam. A mining tool is lowered into the hole to seam level. The tool carries a nozzle which projects high velocity water at the coal, causing it to break away. The nozzle is rotated thus creating a large cylindrical cavity or cavern. A jet pump which is capable of pumping solid particles to the surface offers a simple and low cost solution to the pumping needs.

The two basic techniques for cutting coal by means of jets use either continuous jets of moderate pressure (50 Mpa) or pulsed jets at very high pressures (to 1400 Mpa). The cutting range of a jet is a function of the nozzle diameter, the maximum achieved to date being 1000x diameter or 25 metres.

The use of this technique requires competent roof and floor strata and high horsepowers for jet generation and transportation up the hole. Typically, power required to mine and lift 50 tph through a height of 380 metres is of the order of 1.9 MW. The system is thus likely to have limited application unless the seam thickness in the borehole can offer a large tonnage within reach of the jet.

444 RADIAL MINING - LONGWALL/SHORTWALL

Typical of many mining systems, which are granted patents but which are, in practice, unworkable, is the radial system of longwall and shortwall mining from a large borehole. This variation of longwall or shortwall mining was proposed and patented by Raye, in 1978. In this system a continuous miner working a shortwall face or a double ended ranging drum shearer on a longwall face pivots around a central shaft and excavates a circular block of coal (Figure 4-23). The direction of rotation can be either clockwise or counter clockwise. This system has not been developed or tested to be able to provide actual performance data but some serious concerns must be expressed over the effects of strata movement on the shaft during and after the coal has been extracted, and lack of abutment control on the inner end of the face is considered to be a potential source of roof problems and an area of questionable safety. Doubt must also be expressed about the efficacy of the ventilation system.

445 REMOTELY CONTROLLED MINING SYSTEMS

.1 Introduction

The working and social conditions inherent in the mining industry are such that in times of high employment, the industry has difficulty in maintaining its skilled labour force. At the present time coal can only be brought to the surface from underground deposits by skilled miners who spend their working lives underground in an unpleasant and dangerous working environment. In addition, the miners have to waste a considerable portion of their time underground travelling to their workplace. This further emphasizes the likelihood that in the future, people will be even more reluctant to work in underground coal mines, and surely provides the incentive for the use of automation and robotization in the mines. Progress has to be made to move mining from the "man-in the loop" concept to the "man out of the loop" concept.

Several attempts have been made to remotely operate coal production equipment underground. Attempts in the United Kingdom with the Collins miner in the late 50's and early 60's and with the Remotely Operated Longwall Face (ROLF) relied on an operator working at a console in the roadway adjacent to the working face. These programs failed due to control equipment deficiencies and mining conditions. More recent work in the U.K. is through the Advanced Technology Mining System which combines the best mining systems with the latest in control technology, but even these combinations are a long way from full remote operation. However, before a substantial measure of automation becomes practical, reliable means of controlling the cutting horizon of the coal producing machine and also of controlling face or development heading alignment and direction are required.

Mining is a relative latecomer in the utilization of such high technology as automation and robotics in its operations. Current efforts are limited to the introduction of remote control and monitoring systems in underground coal mines which are able to make a direct contribution to improving productivity. The control and monitoring of transportation systems, pumps, ventilation and the underground environment are already commonplace in many mines in Europe and North America.

It is not that mining engineers, who by nature are technically conservative, are unaware of the potential production gains which would be realized with the use of some aspect of high technology in mining. They are certainly aware of the many successful uses of high technology in the space, nuclear, manufacturing and processing industries. There are however several factors unique to mining which tend to impede the rapid introduction of new high technology and robotics into mining. These include:

- the constantly changing geometry of the mine workings and the unpredictability of the working conditions;

- an underground environment which is extremely hostile to equipment, especially control equipment;

- in mining, the robot has to be mobile with a working face being advanced, rather than a stationary robot as used in other industries;

- acceptance of new equipment and concepts is a long process in mining, since a bad decision can have disastrous consequences on the engineer's and his company's survival.

The development of equipment for automation does not necessarily have to follow existing mining methods. Mining methods for the future may have to be modified to suit the new concepts and equipment, and it is quite likely that the successful application of robotic automation in mining will only materialize with the development of new mining concepts.

It must be recognized that the use of robotics in mining will necessitate developments in technology which are far different from those being successfully used in the processing and manufacturing industries, but perhaps may be not too dissimilar from the concepts currently being developed in the USA for mining in space.

One of the major problems to be faced is the lack of knowledge of engineers involved in mining and in robotics of each others needs, areas of expertise and research and development. A meeting of minds is obviously called for.

In considering the development of robots for mining use, and recognizing the operational requirements and environmental conditions which exist in coal mines, particular attention must be paid to the following factors:

- sensing, monitoring and control equipment;
- reliability and robustness;
- safety;
- flexibility
- intelligence
- ease of maintenance and repair.

These factors should be studied as "elements" in an actual underground environment, and when proved successful, integrated into system studies.

The robotic industry is on the verge of major advances in programmed intelligence, a commodity which can be considered essential to cope with the harsh and variable mining environment and the range of different variables and situations that will be encountered.

There are ore deposits, such as the high concentration (35%) uranium deposits in Saskatchewan, or the coal seams at depth under the ocean (4,000 m under the North Sea), which cannot be mined conventionally by people working within the deposit.

In the long term, it will clearly be necessary to develop new mining methods and machinery to take fullest advantage of the fact that people are not at risk mining these deposits which are beyond present mining technology.

Even though the need for this new technology is unlikely to occur before the end of this century, the long lead time required indicates that it is not too soon to start now to devote research and development effort to robotic mining systems.

Some ideas have already been put forward, two of which, mole mining and telechiric mining are briefly described below.

.2 Remote Controlled Mole Mining

Conceptual studies have been carried out into the applicability of self-contained, remotely operated coal cutting and transportation systems that could drive very small self supporting coal roadways and, because they are not attended by humans, be able to operate in remote unsupported and non-ventilated areas.

Typical of this style of mining is the Tube System proposed by Professor Thring. A single miner would be connected to the surface by cables and flexible tubes. The miner would excavate a circular hole in the seam and drive to the length of its supply umbilical. It would then return to the main shaft and bore another hole alongside the first hole, but separated from it by a small pillar of coal left for roof support (Figure 4-24).

Assessments of the practicality of such systems by experienced coal mine operators has resulted in many questions that the remote system advocates have as yet been unable to fully answer. Some of these unanswered questions are:

- o Coal clearance and transportation, how is it maintained and operated over long distances and how can the mole pull this equipment along behind it.
- o Electrical cables and hose have the same problems as the coal transportation system.
- o How can a small fall of rock on the coal transportation or cable and hoses systems be removed since the mole would be trapped by the fall and could not retreat back to clear it.

- o How does the mole reverse direction to get out of unforeseen and unmanageable conditions.

- o When the strata pressure reduces the roadway size behind the mole how can it retreat.

By using remote control of existing mining systems, reductions in the number of personnel required and their exposure to accidents, airborne dust and fatigue is said to increase overall system performance and through this provide a rapid pay back for the capital expended. Remote control is expected to play an increasing part in the overall underground mining scheme as it has many advantages and unlike the fully Telechiric system discussed below, should be easier to fully develop and install.

.3 Remotely Controlled Telechiric Mining

Telechiric mining is the expression most often used for the mining systems that use special remotely controlled machines that have mechanical or mechanical-electrical arms, hands, legs, eyes, ears and as such can relay such sensations as touch, sight, etc., to a human located some distance away, "hands at a distance". By using the relayed information the human can control all of the machine's functions through a two-way communication system.

The most recent and comprehensive work on Telechirics has been carried out over the last 30 years in America and more recently in France by those interested in the remote handling of highly radioactive materials and in remote manipulation in space applications. More recently a great deal of interest in this field has come from the concept of drilling for oil from the bottom of the sea and for carrying out operations on wells drilled from platforms in the sea.

A great deal of work has been done on power systems and mechanical master/slave arm systems are available on the market incorporating a measure of force feedback so that the human can feel when the hand is grasping an object or the weight of the object he has picked up.

Nevertheless, it can be concluded that without discovering any new basic principles it is possible to design a mining telechir such that a human miner on the surface can carry out the essential parts of any task which he would normally do on the spot down a mine. Telechiric mining can be described as a human miner carrying out any task that he would do down the mine, such as controlling machines to cut roadways, the erection of supports, the installation of coal mining and transport machinery, its operation, diagnosis of breakdowns and repairs, with sufficient skill as though he were on the spot down the mine (Figure 4-25).

In the case of an underground mine it has been suggested that such remotely controlled machines could be installed in a mine and not only carry out all the mining functions that are presently carried out by humans, e.g. operate coal mining machines, etc., but also carry out maintenance to that machinery and, in certain cases to each other (major maintenance and repair to the robot would be carried out on the surface by humans). As similar machines have been successfully used to carry out projects on the moon it is reasonable to expect that technically they can be so designed to work in a coal mine environment. In fact some researchers feel that such devices could be designed to work continuously 365 days per year, not have to travel into or out of the mine at shift change, not stop for meals, be able to work in locations that have insufficient oxygen to support human life (little or no ventilation required). The list of potential advantages is considerable. Unfortunately, not only would the technology be very expensive to develop and install but its other disadvantages include the machine's inability to think and prevent accidents occurring to itself and to the mine, and many of the same mobility problems associated with the 'mole' mining systems.

It is also a well-known law of engineering that the more one automates the more ingeniously the system finds new ways to break down for which no allowance has been made (Murphy's Law?). These breakdowns require the adaptability, observational ability and skill of a human craftsman to locate the fault, diagnose exactly what is wrong and repair it.

The major advantages foreseen for telechiric mining are:

- removal of personnel from the underground environment;
- minimum ventilation required (heat dissipation);
- no working time lost transporting personnel to their working place which would now be on the surface;
- safer working environment.

However, it is unlikely that telechiric mining will be developed to the operating state for many decades, since the easier and more logical next step is to concentrate on perfecting remote control of mining equipment from underground control stations close to the working face, but with the vast amount of research and development obviously required to bring the telechiric mining systems to commercial viability, work should be started as soon as possible to define the telechiric mining system requirements and concepts.

TABLE 4-1

Face Heights That Can Be Cut

Drum Diameter (metres)		Length of Ranging Arm (millimetres)		
		250	500	750
1.4	maximum	1.9	2.4	2.9
	minimum	1.65	1.9	2.15
1.6	maximum	2.1	2.6	3.1
	minimum	1.85	2.1	2.35
1.8	maximum	2.3	2.8	3.3
	minimum	2.05	2.3	2.55

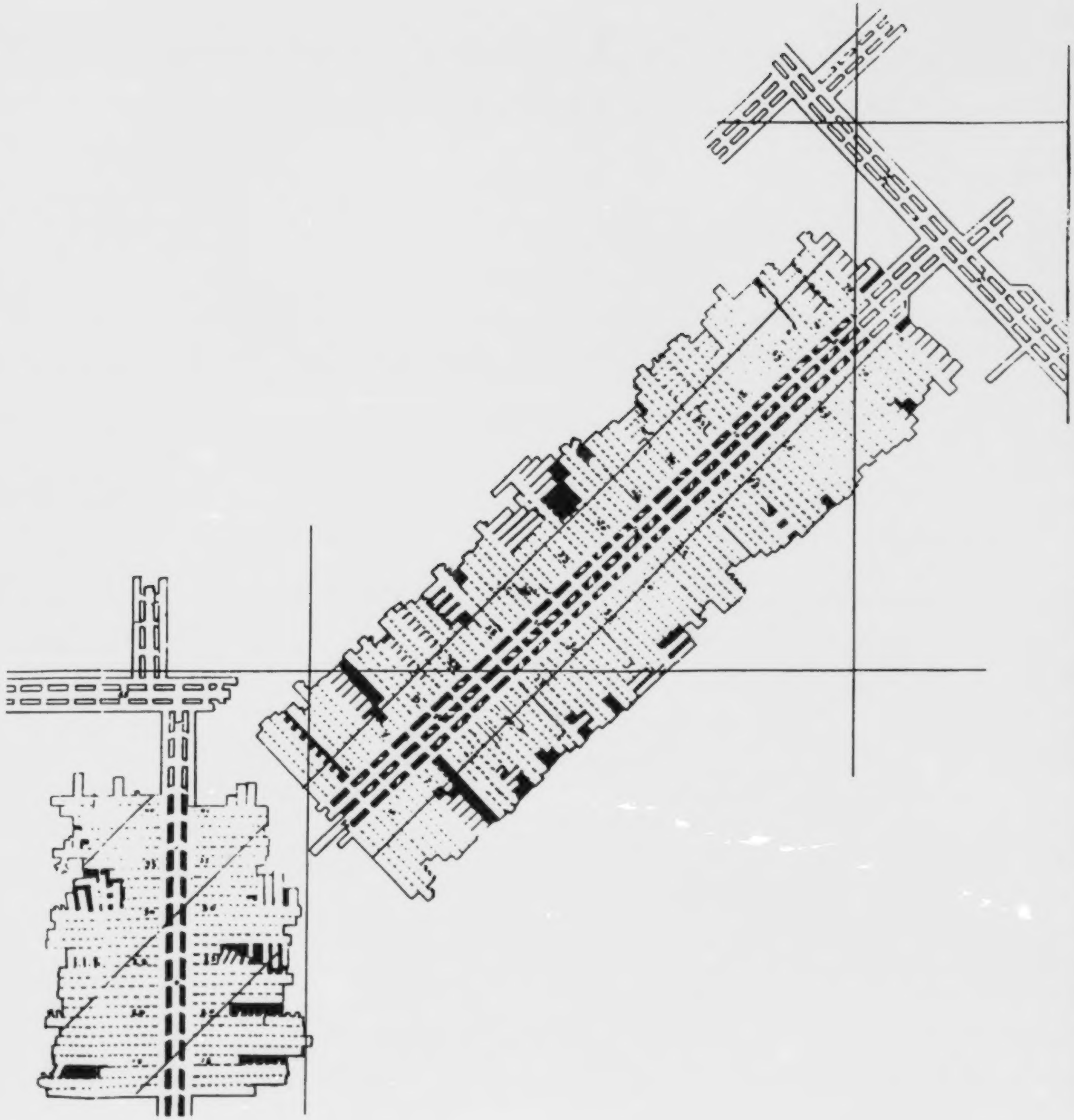


FIGURE 4-1 PLAN SHOWING TYPICAL SHORTWALL SYSTEM A WITH YIELDING PILLARS

(COURTESY AMAX CHEMICAL CORP.)

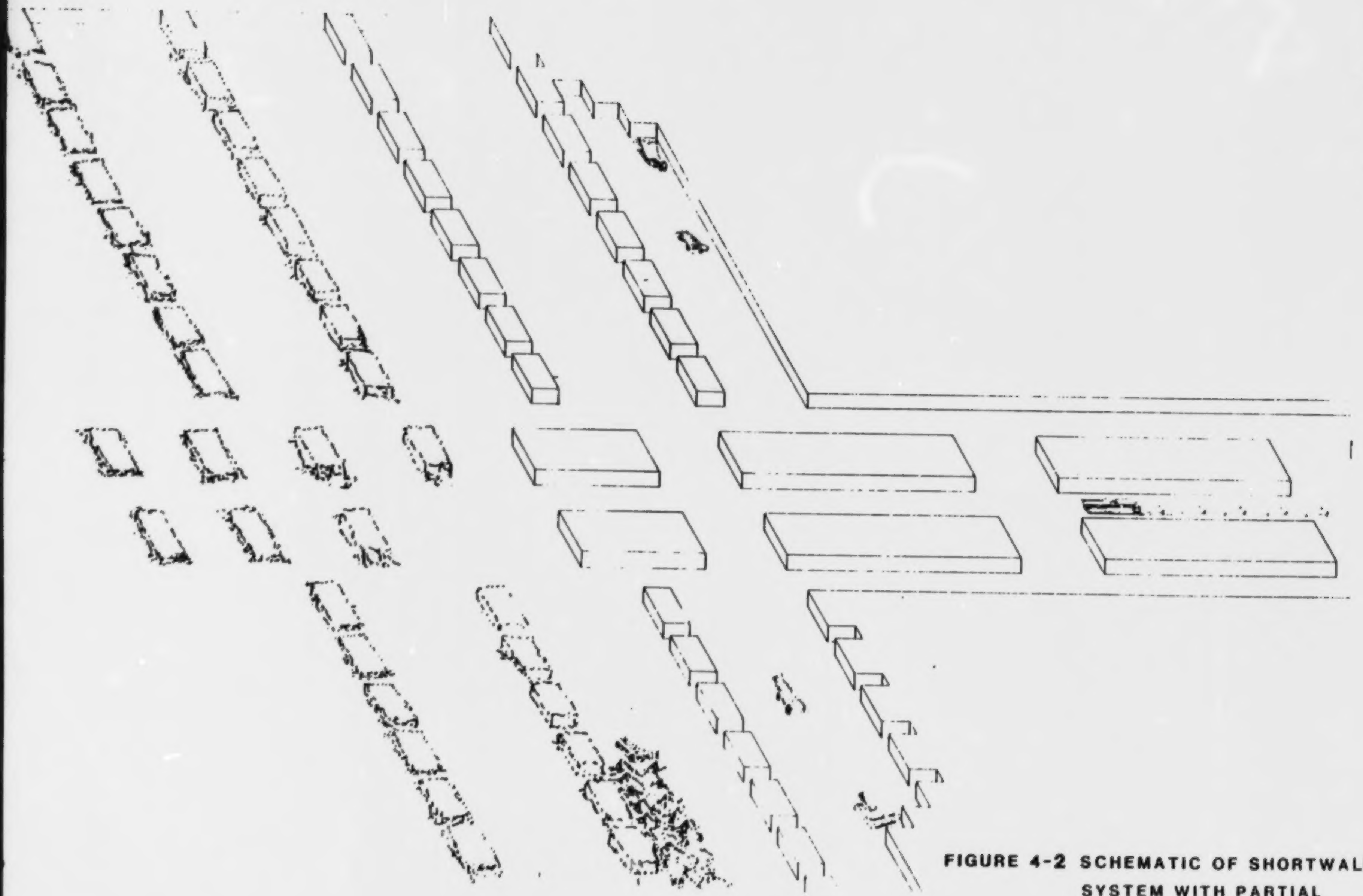
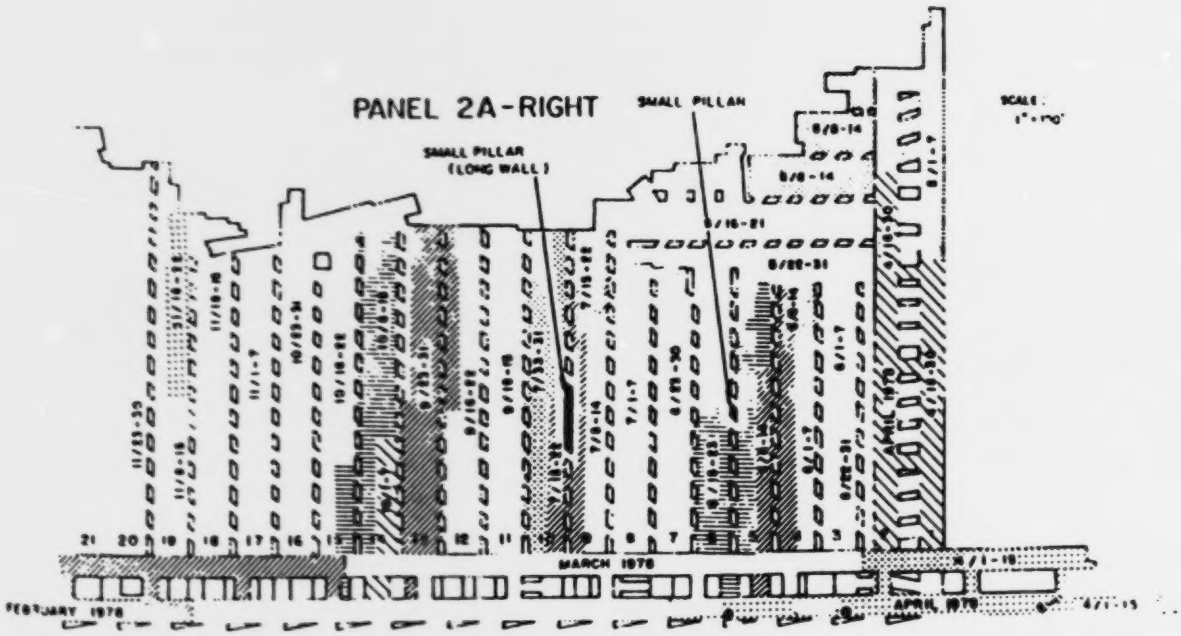


FIGURE 4-2 SCHEMATIC OF SHORTWALL SYSTEM WITH PARTIAL BACKFILL

(COURTESY MISSISSIPPI CHEMICAL CORP.)


PANEL 2A-RIGHT
SMALL PILLAR
SMALL PILLAR (LONG WALL)
SCALE:
MARCH 1978
FEBRUARY 1978
APRIL 1979
21
20
19
18
17
16
15
12
11
9
8
7
5
3

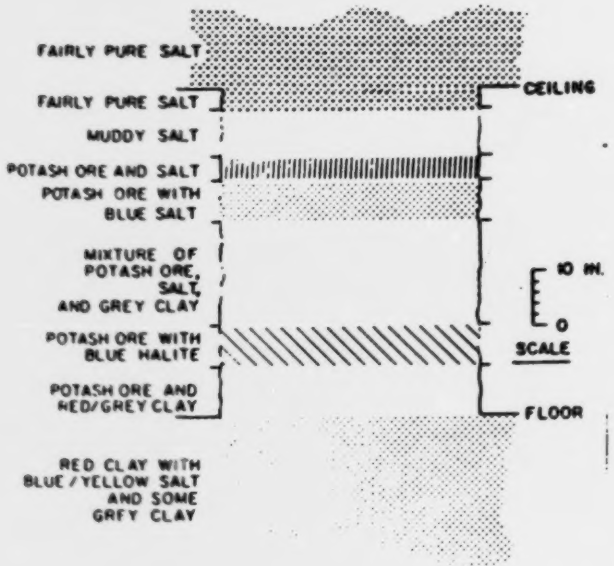

FAIRLY PURE SALT
FAIRLY PURE SALT
CEILING
MUDDY SALT
POTASH ORE AND SALT
POTASH ORE WITH BLUE SALT
MIXTURE OF POTASH ORE, SALT, AND GREY CLAY
10 IN.
0
SCALE
POTASH ORE WITH BLUE HALITE
POTASH ORE AND RED/GREY CLAY
FLOOR
RED CLAY WITH BLUE/YELLOW SALT AND SOME GREY CLAY

FIGURE 4-3 LOCATION OF PILLARS IN SHORTWALL MINING FOR CONVERGENCE TESTS

(COURTESY AMAX CHEMICAL CORP.)

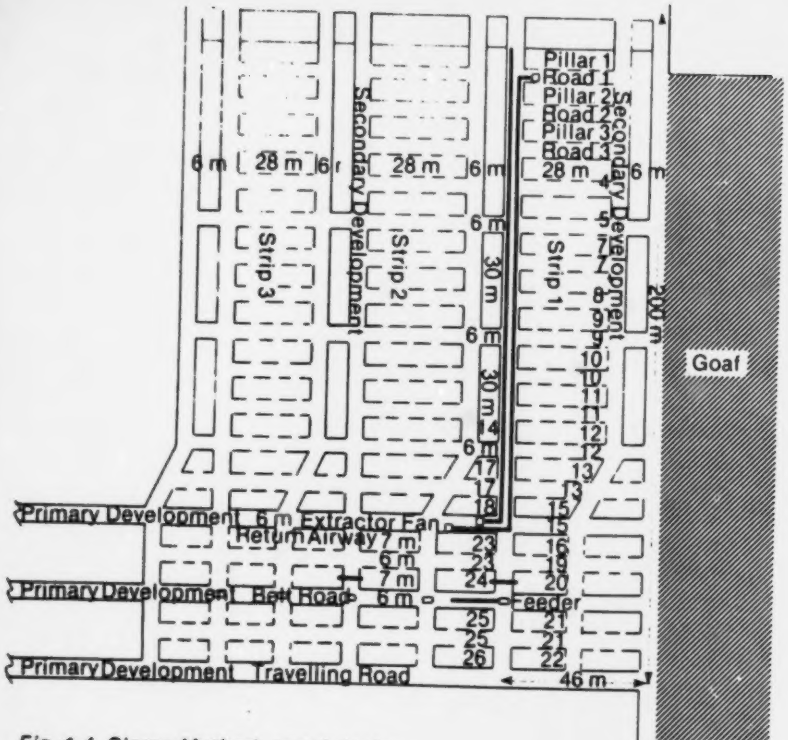

Goaf
200 m
Secondary Development
Pillar 1
Road 1
Pillar 2
Road 2
Pillar 3
Road 3
28 m
6 m
Strip 1
Strip 2
Strip 3
30 m
46 m
Primary Development
6 m
Extractor Fan
Return Airway
7 m
Belt Road
Feeder
Travelling Road

Fig. 4.4. Sigma Method: panel design.

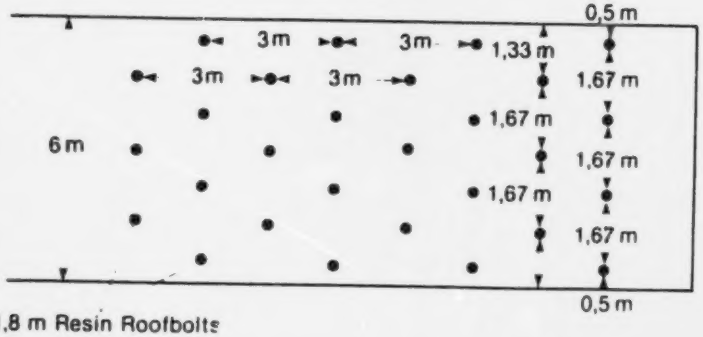

0,5 m
3m
1,33 m
1,67 m
6 m
0,5 m
1,8 m Resin Roofbolts

Fig. 4.5. Sigma Method: roof support for primary and secondary development

(COURTESY SAIMM)

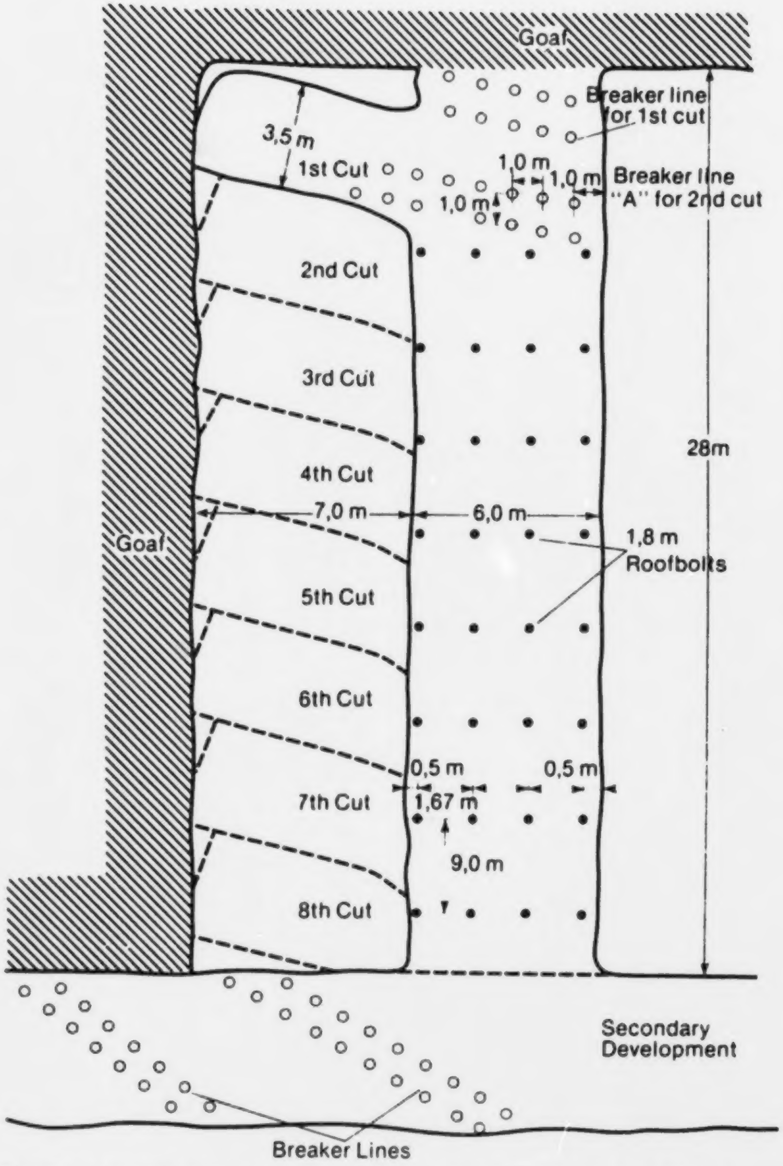

Goaf
Breaker line for 1st cut
Breaker line "A" for 2nd cut
3,5 m
1st Cut
1,0 m
2nd Cut
3rd Cut
4th Cut
5th Cut
6th Cut
7th Cut
8th Cut
7,0 m
6,0 m
28m
1,8 m Roofbolts
0,5 m
1,67 m
9,0 m
Goaf
Secondary Development
Breaker Lines

Fig. 4.6. Sigma Method: sequence of cuts for the extraction of pillars.

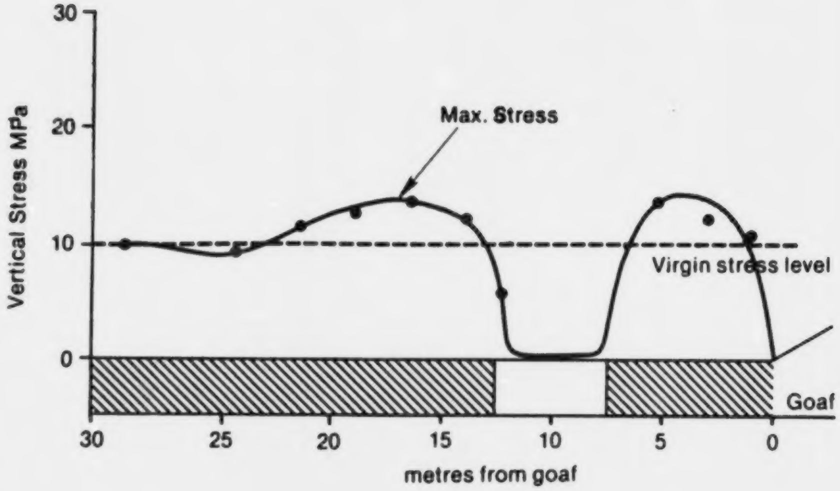
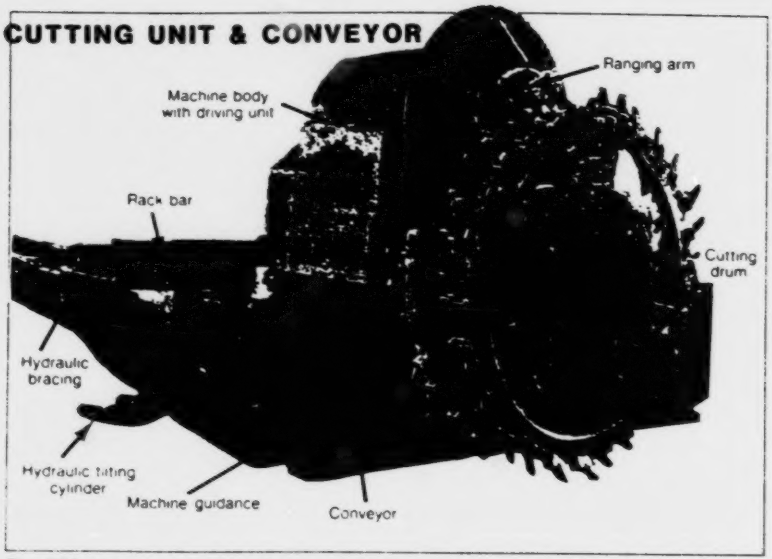


FIGURE 4-7 RIB PILLAR EXTRACTION: VERTICAL STRESS DISTRIBUTION FOR A RIB OF 7.5m

(COURTESY SAIMM)

FIGURE 4-8 ESA CUTTING UNIT & CONVEYOR


Ranging arm
Machine body with driving unit
Rack bar
Cutting drum
Hydraulic bracing
Hydraulic tilting cylinder
Machine guidance
Conveyor

The ESA design is based on the shearer-loader principle and therefore represents a step forward in technological development, allowing for driving of arched or rectangular roadways.

FIGURE 4-9(a) ROAD CUTTER WITH FEEDER BREAKER

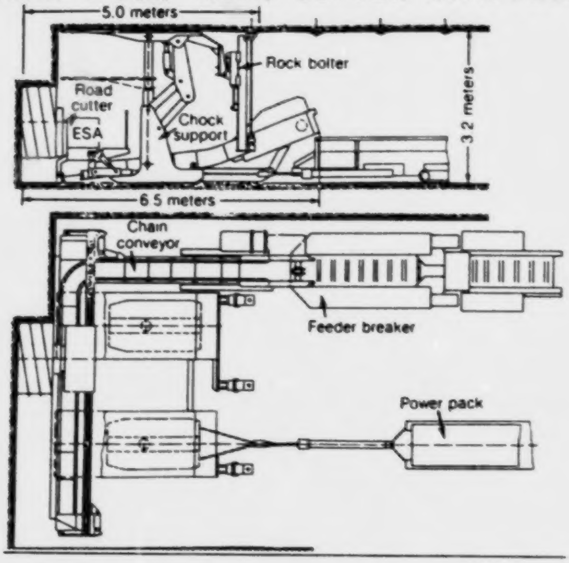

5.0 meters
Rock bolter
Road cutter
ESA
Chock support
3.2 meters
6.5 meters
Chain conveyor
Feeder breaker
Power pack

FIGURE 4-9(b) ROAD CUTTER WITH BRIDGE CONVEYOR

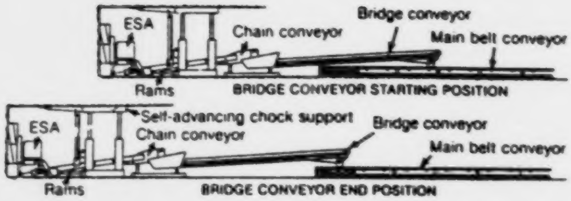
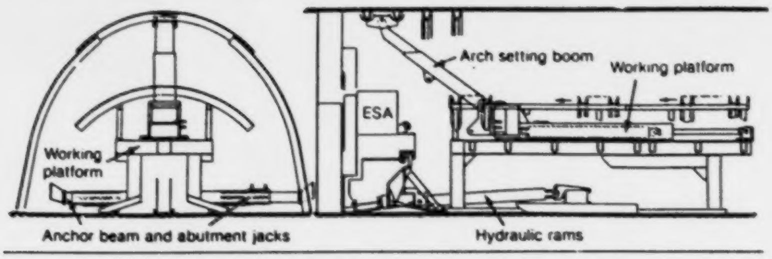

ESA
Chain conveyor
Bridge conveyor
Main belt conveyor
Rams
BRIDGE CONVEYOR STARTING POSITION
ESA
Self-advancing chock support
Chain conveyor
Bridge conveyor
Main belt conveyor
Rams
BRIDGE CONVEYOR END POSITION

FIGURE 4-10 ROAD CUTTER AND SETTING DEVICE FOR ARCH ROOF SUPPORT


Working platform
Anchor beam and abutment jacks
Arch setting boom
Working platform
ESA
Hydraulic rams

(COURTESY ATLAS COPCO CANADA)

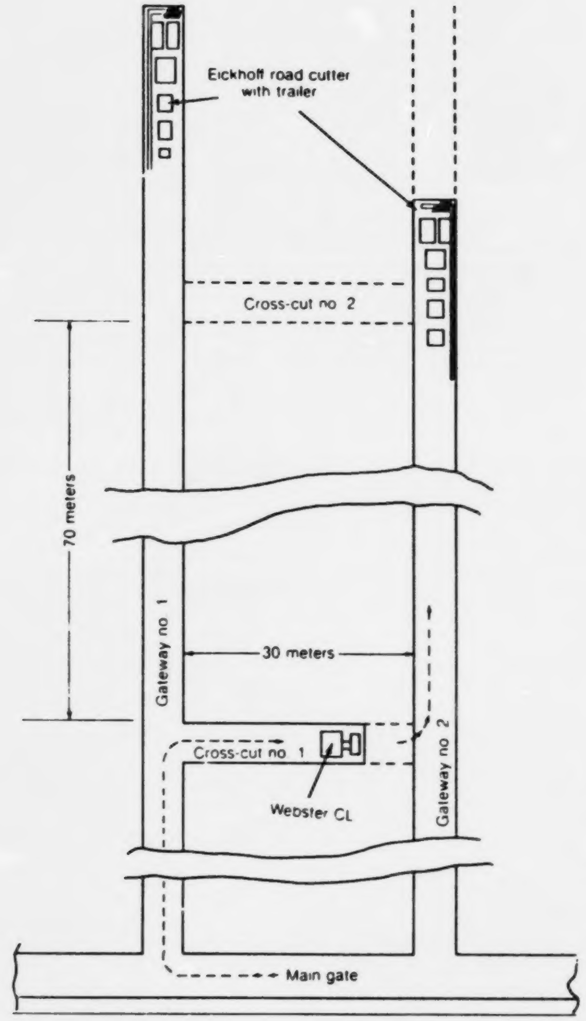
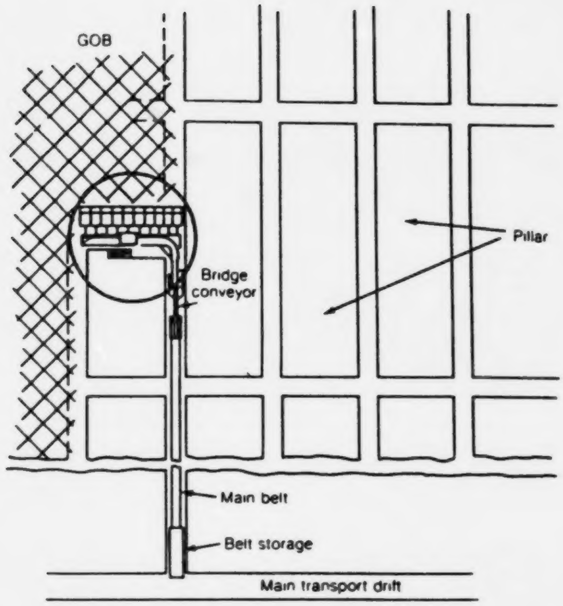

Eickhoff road cutter with trailer
Cross-cut no 2
70 meters
30 meters
Gateway no 1
Gateway no 2
Cross-cut no 1
Webster CL
Main gate

FIGURE 4-11
DRIVING DOUBLE ENTRIES


GOB
Pillar
Bridge conveyor
Main belt
Belt storage
Main transport drift

SITUATION TO BIGGER SCALE

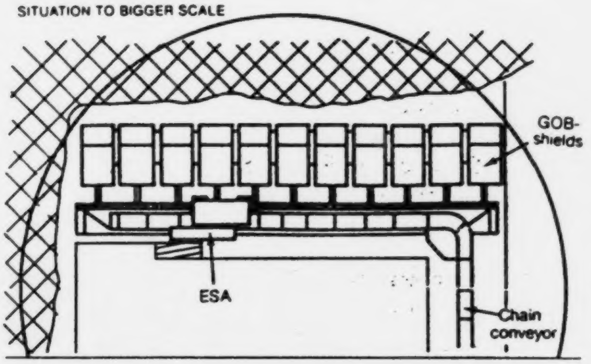

GOB-shields
ESA
Chain conveyor

FIGURE 4-12
PILLAR RECOVERY WITH ESA

(COURTESY ATLAS COPCO CANADA)

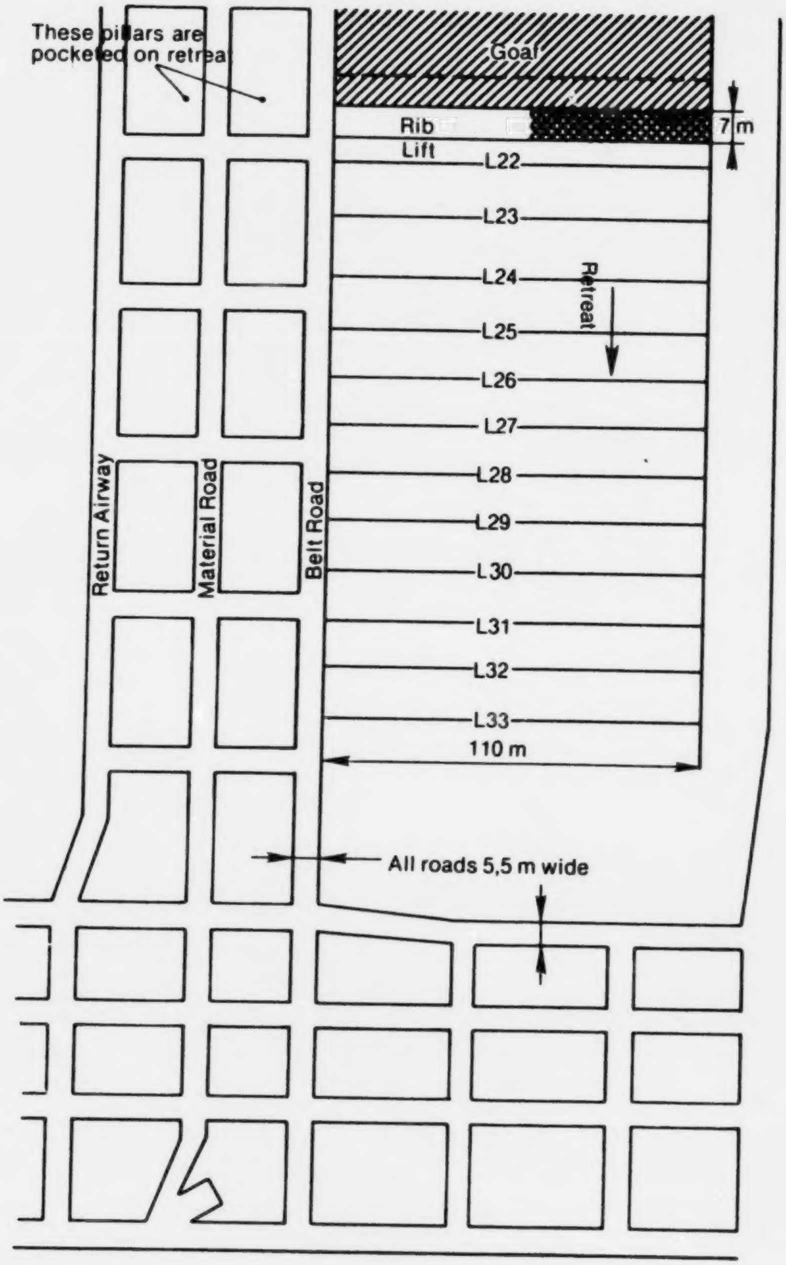
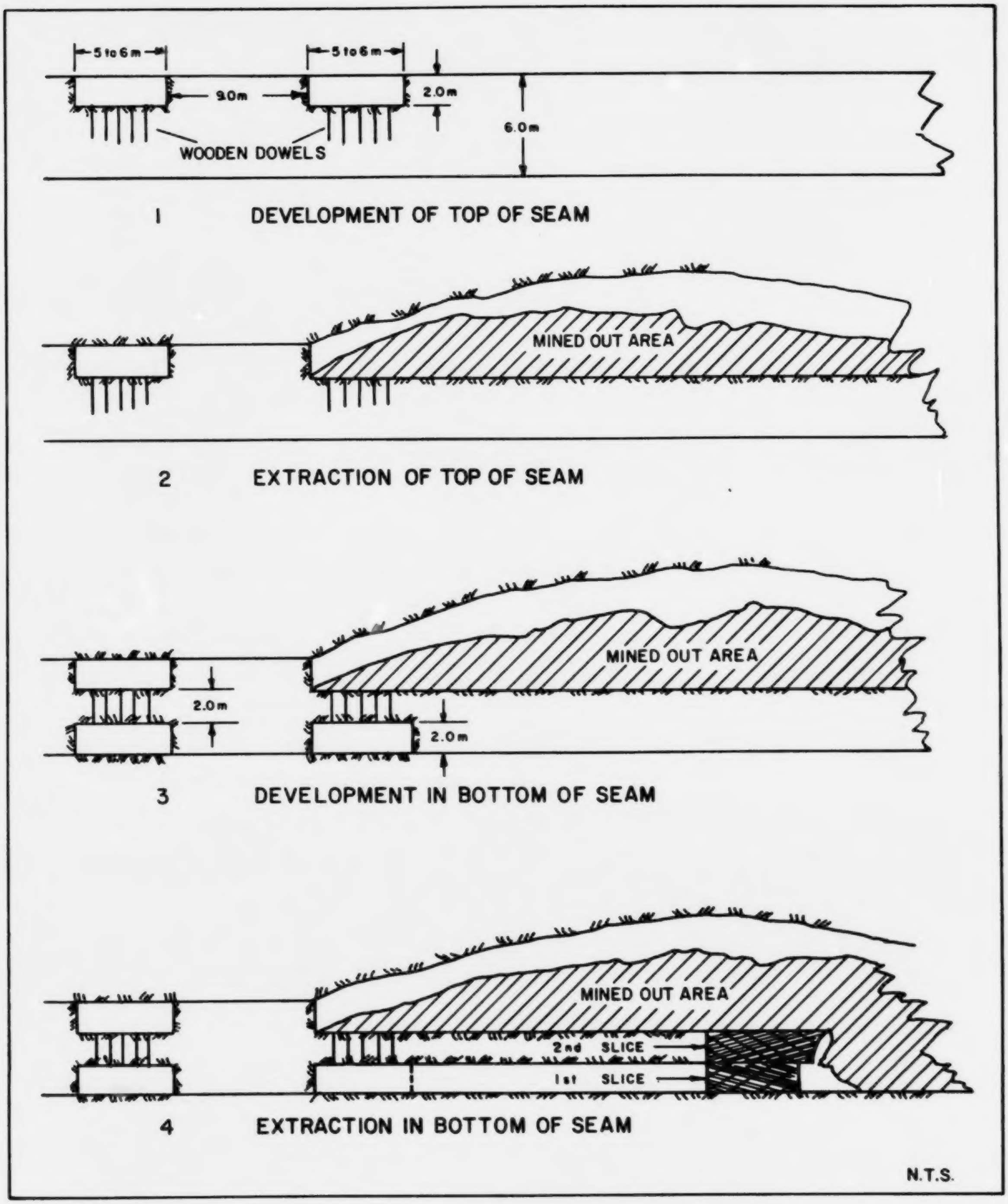

These pillars are pocketed on retreat
Goal
Rib
Lift
7 m
L22
L23
L24
L25
L26
L27
L28
L29
L30
L31
L32
L33
Retreat
110 m
Return Airway
Material Road
Belt Road
All roads 5,5 m wide

FIGURE 4-13 THE WONGAWILLI METHOD

(COURTESY SAIMM)


5 to 6m
5 to 6m
9.0m
2.0m
6.0m
WOODEN DOWELS
MINED OUT AREA
MINED OUT AREA
2.0m
2.0m
MINED OUT AREA
2nd SLICE
1st SLICE
N.T.S.

1 DEVELOPMENT OF TOP OF SEAM

2 EXTRACTION OF TOP OF SEAM

3 DEVELOPMENT IN BOTTOM OF SEAM

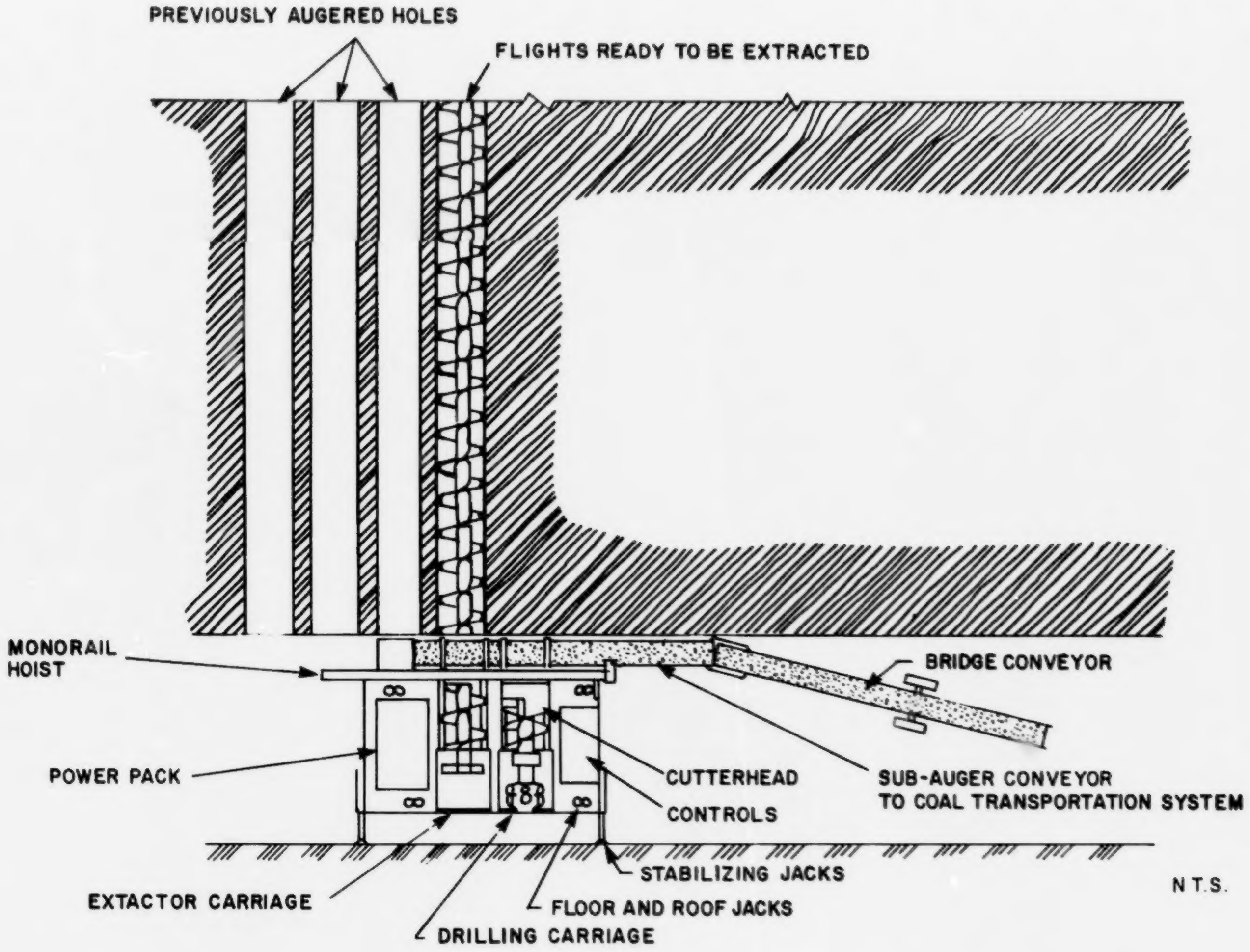
4 EXTRACTION IN BOTTOM OF SEAM

FIGURE 4-14 THICK SEAM "TWO LIFT" WONGAWILLI SYSTEM SECTIONS OF DEVELOPMENT AND EXTRACTION SEQUENCE

(COURTESY ACIRL.)

FIGURE 4-15

PLAN VIEW OF COAL AUGERING DEVICE WITH TWO CARRIAGES


PREVIOUSLY AUGERED HOLES
FLIGHTS READY TO BE EXTRACTED
MONORAIL HOIST
BRIDGE CONVEYOR
POWER PACK
CUTTERHEAD
CONTROLS
SUB-AUGER CONVEYOR TO COAL TRANSPORTATION SYSTEM
STABILIZING JACKS
EXTACTOR CARRIAGE
FLOOR AND ROOF JACKS
DRILLING CARRIAGE
N T.S.

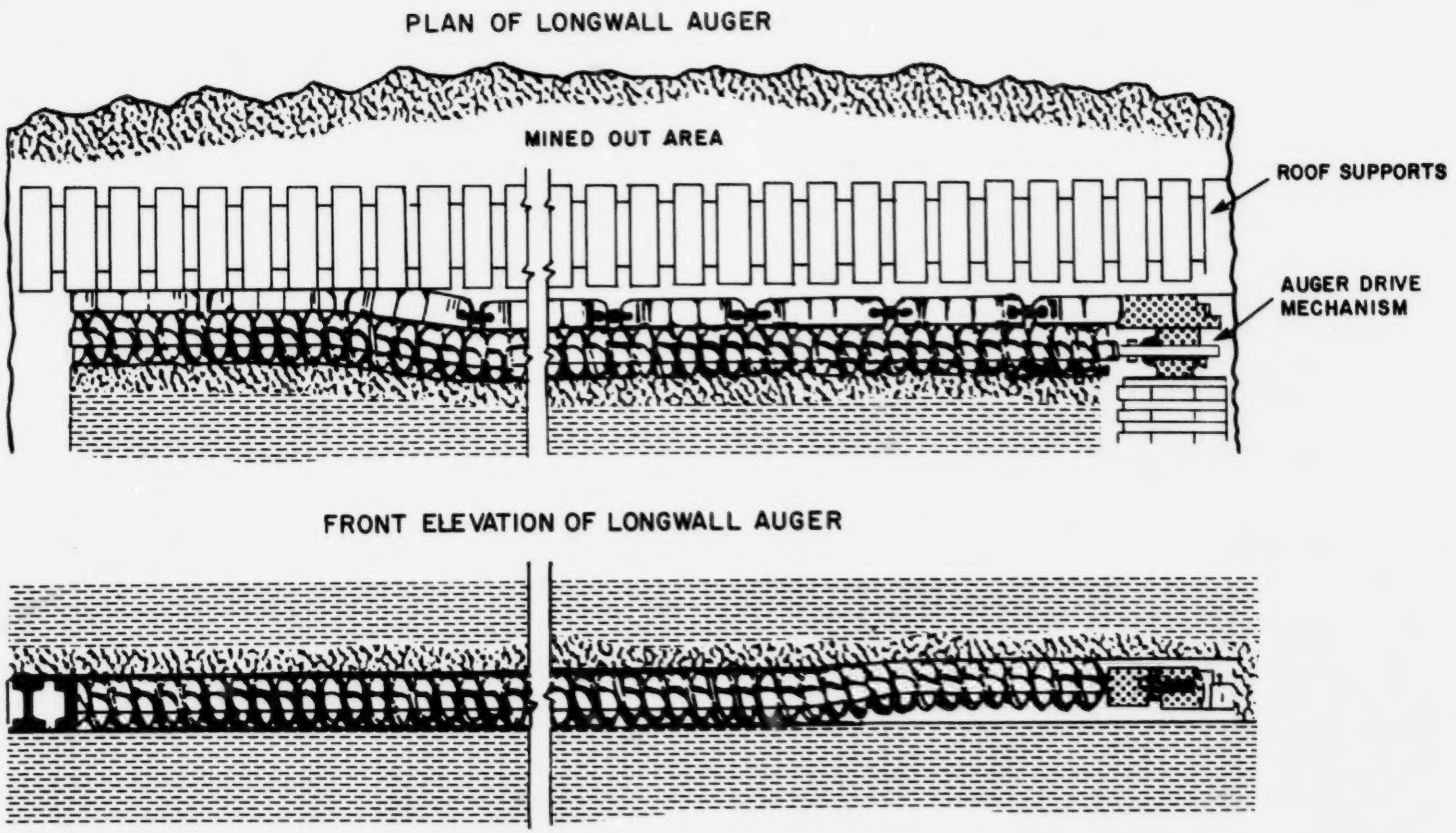

PLAN OF LONGWALL AUGER
MINED OUT AREA
ROOF SUPPORTS
AUGER DRIVE MECHANISM
FRONT ELEVATION OF LONGWALL AUGER

FIGURE 4-16 SCHEMATIC REPRESENTATION OF THE VARIABLE WALL MINING SYSTEM

N.T.S.

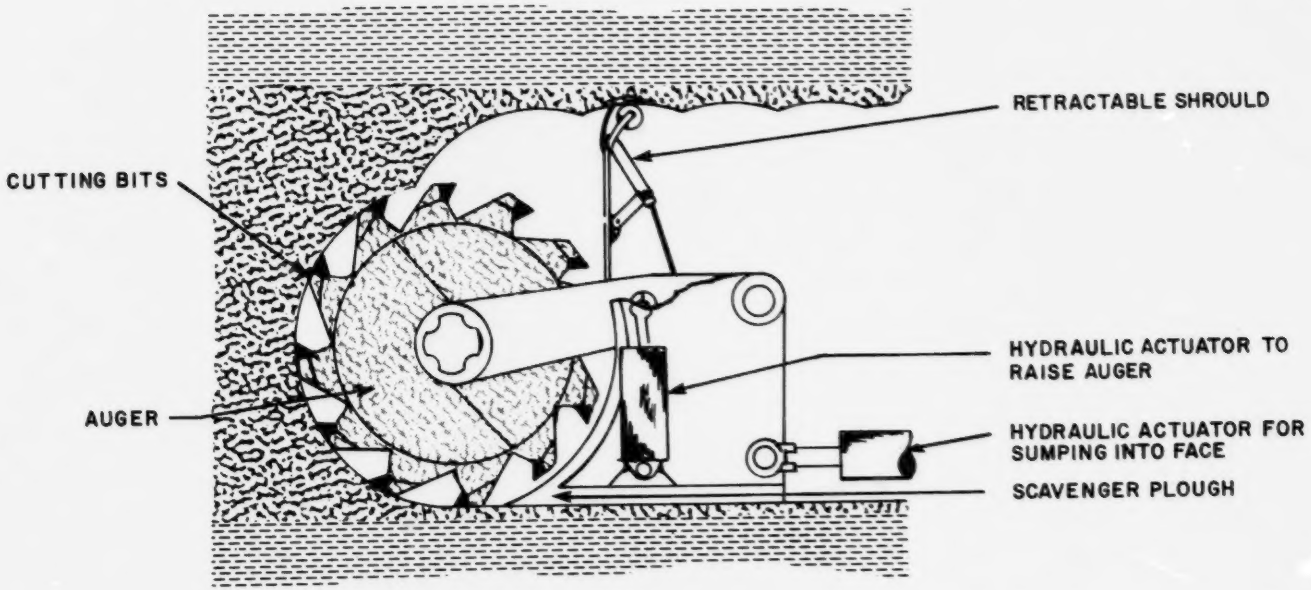

RETRACTABLE SHROULD
CUTTING BITS
HYDRAULIC ACTUATOR TO RAISE AUGER
AUGER
HYDRAULIC ACTUATOR FOR SUMPING INTO FACE
SCAVENGER PLOUGH

FIGURE 4-17 SCHEMATIC REPRESENTATION OF THE VARIABLE WALL MINING SYSTEM

END VIEW OF LONGWALL AUGER SUMPING IN

NTS

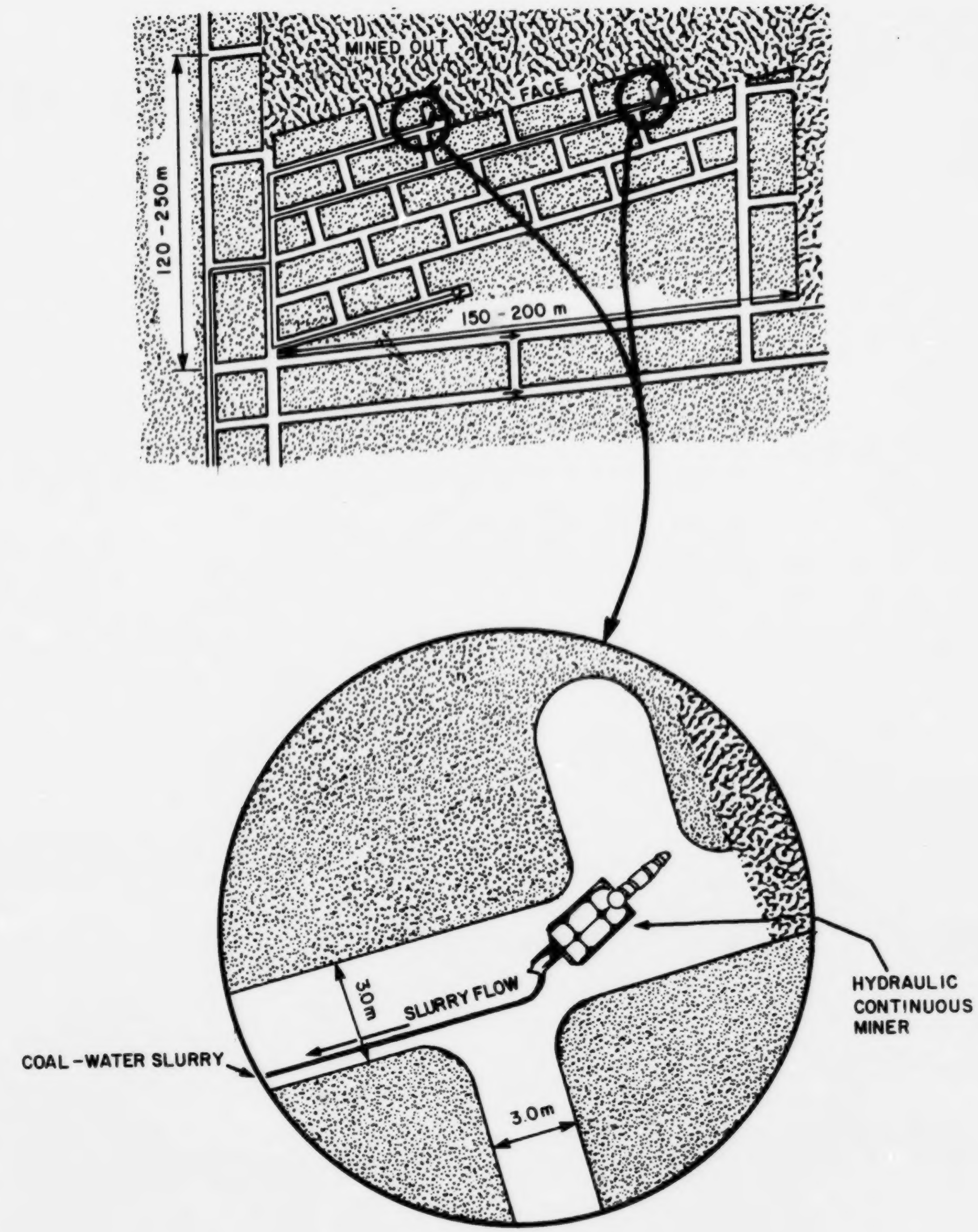
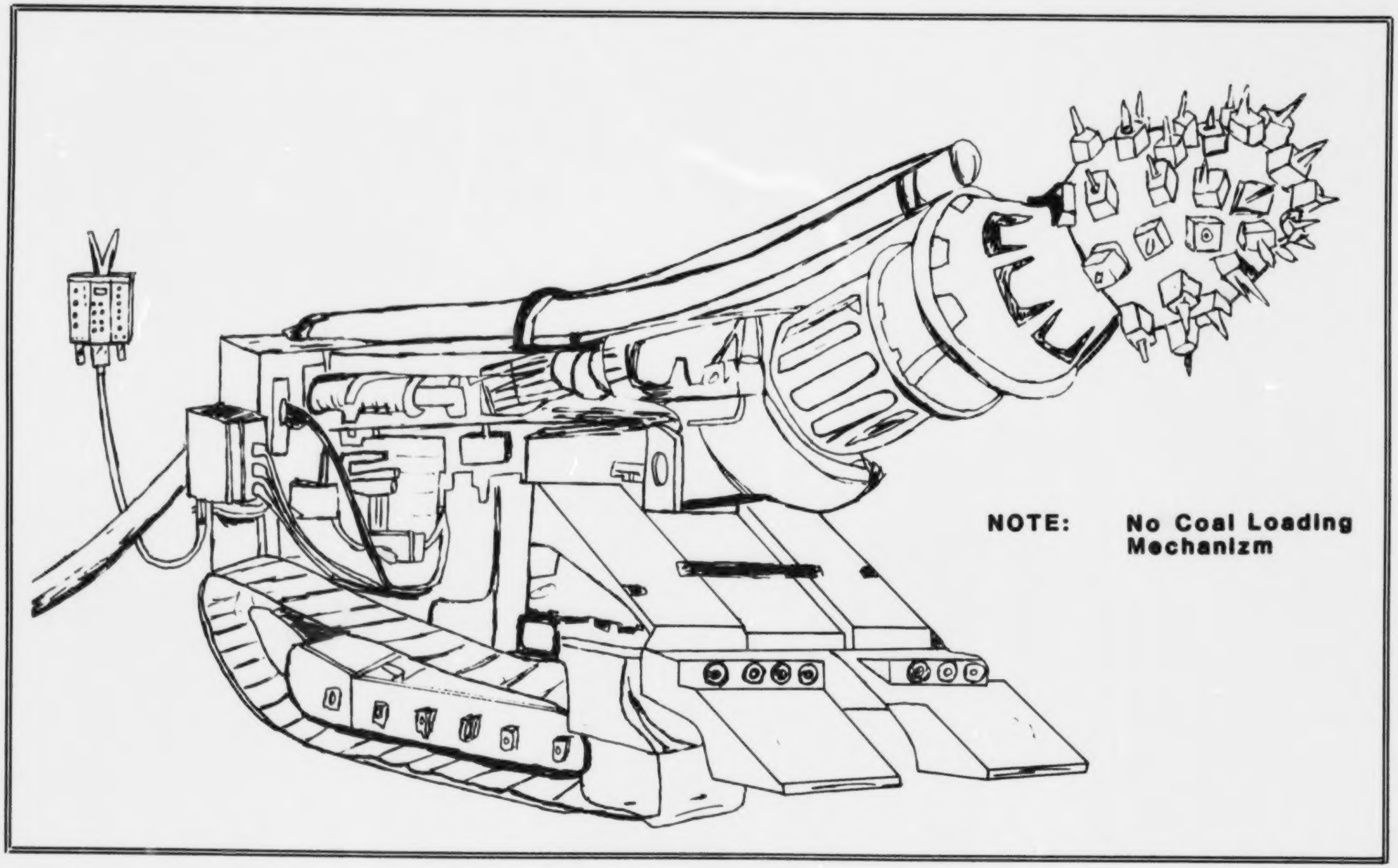
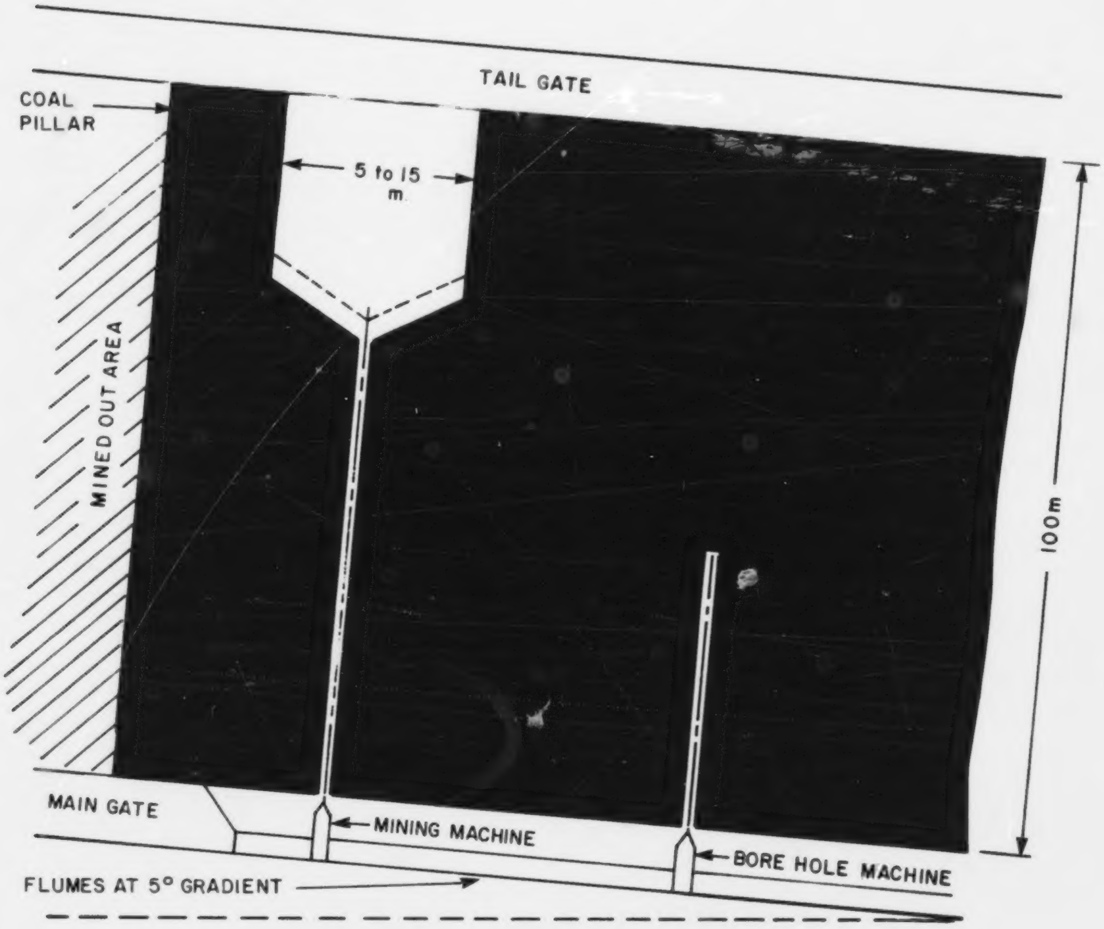

MINED OUT
FACE
120 - 250 m
150 - 200 m
3.0 m
SLURRY FLOW
COAL-WATER SLURRY
3.0 m
HYDRAULIC CONTINUOUS MINER

FIGURE 4-18
HYDRAULIC NARROW EXCAVATION ROOM AND PILLAR MINING



NOTE: No Coal Loading Mechanizm

FIGURE 4-19
TYPICAL HYDRAULIC CONTINUOUS MINER COMPLETE WITH HYDRAULIC TRANSPORTATION & REMOTE CONTROLS FOR GRAVITY HYDRAULIC ROOM & PILLAR MINING


TAIL GATE
COAL PILLAR
5 to 15 m
MINED OUT AREA
100m
MAIN GATE
MINING MACHINE
BORE HOLE MACHINE
FLUMES AT 5° GRADIENT

N.T.S.

FIGURE 4-20

BOREHOLE HYDRAULIC MINING

(DOWNWARDS)

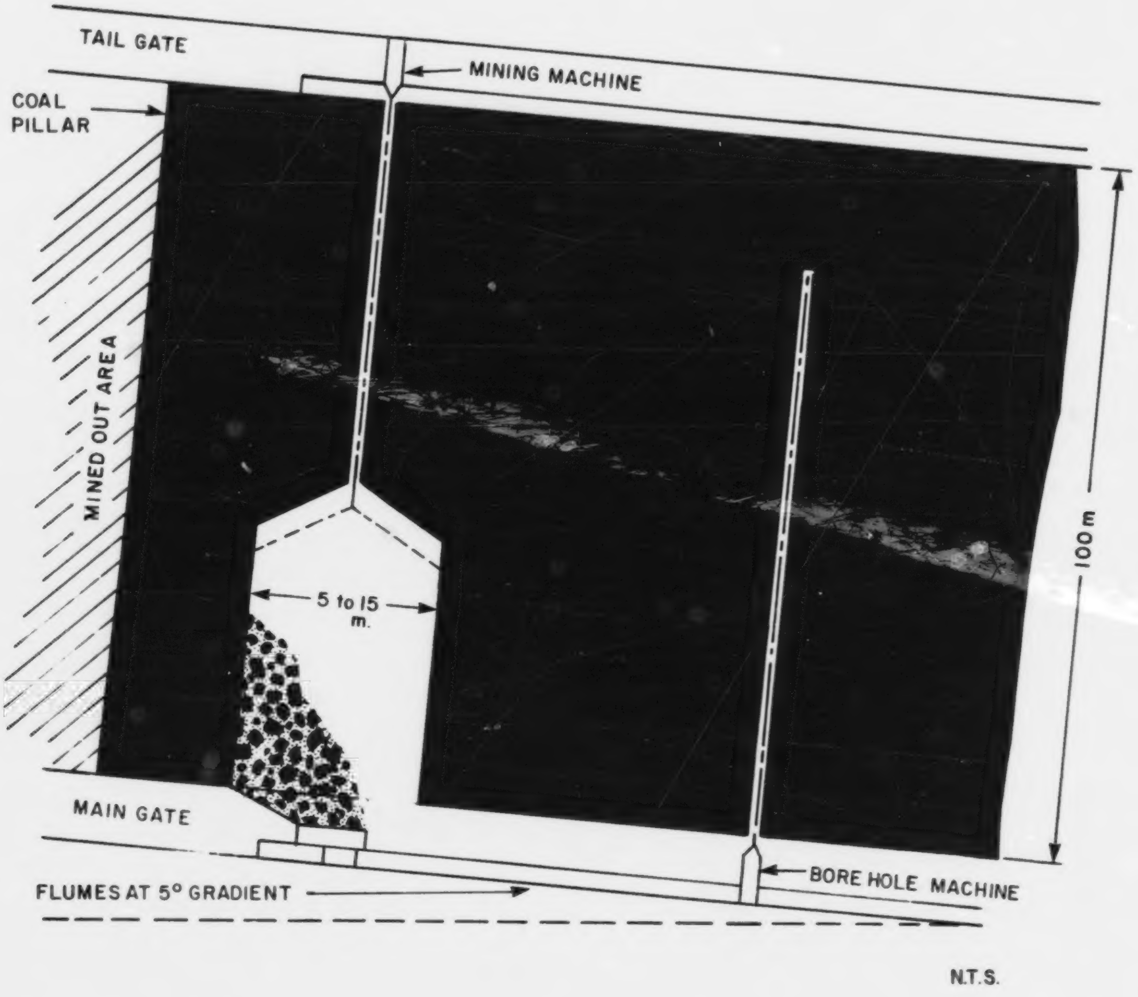

TAIL GATE
MINING MACHINE
COAL PILLAR
MINED OUT AREA
5 to 15 m.
100 m
MAIN GATE
FLUMES AT 5° GRADIENT
BORE HOLE MACHINE
N.T.S.

FIGURE 4-21

BOREHOLE HYDRAULIC MINING

(UPWARDS)

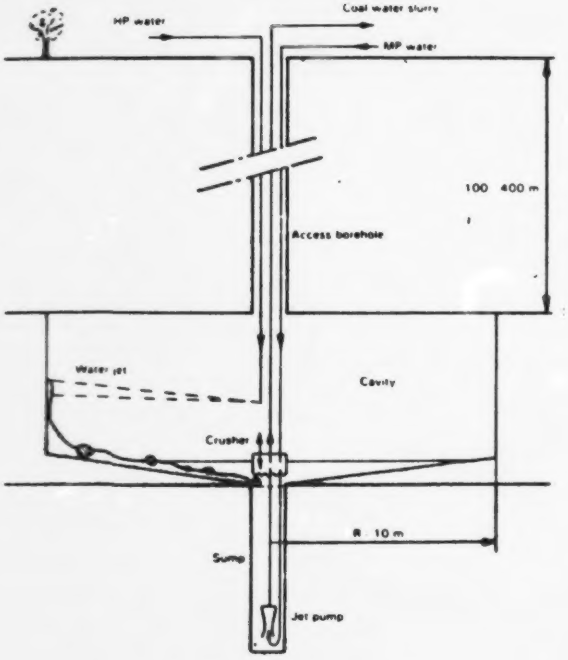

HP water
Coal water slurry
MP water
100 400 m
Access borehole
Water jet
Cavity
Crusher
R 10 m
Sump
Jet pump

FIGURE 4-22 SCHEMATIC OF BOREHOLE (CAVITY) MINING

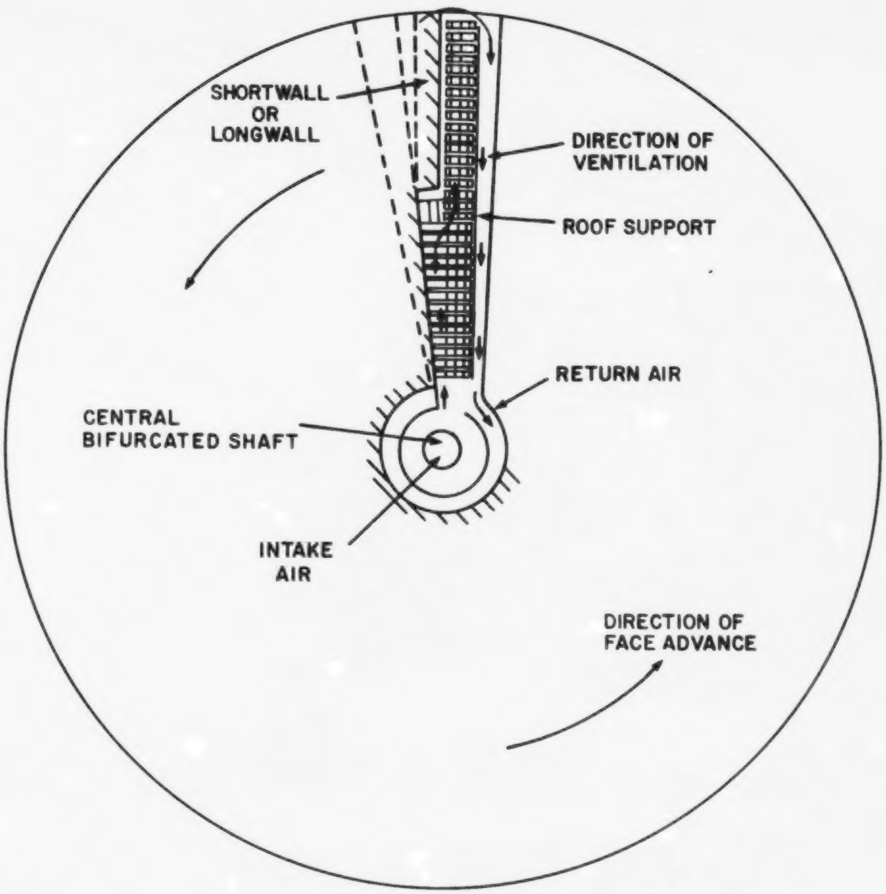

SHORTWALL OR LONGWALL
DIRECTION OF VENTILATION
ROOF SUPPORT
RETURN AIR
CENTRAL BIFURCATED SHAFT
INTAKE AIR
DIRECTION OF FACE ADVANCE

FIGURE 4-23

RADIAL MINING METHOD

N.T.S.

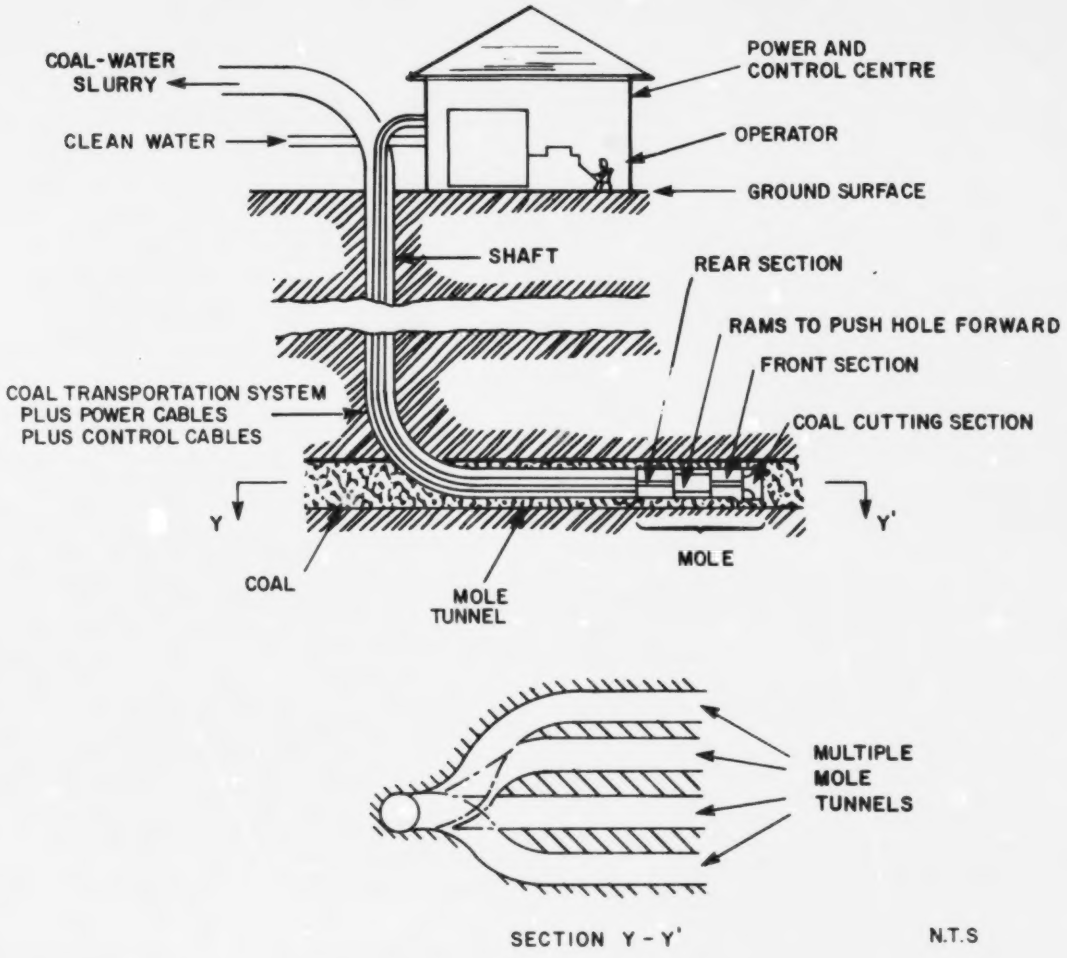
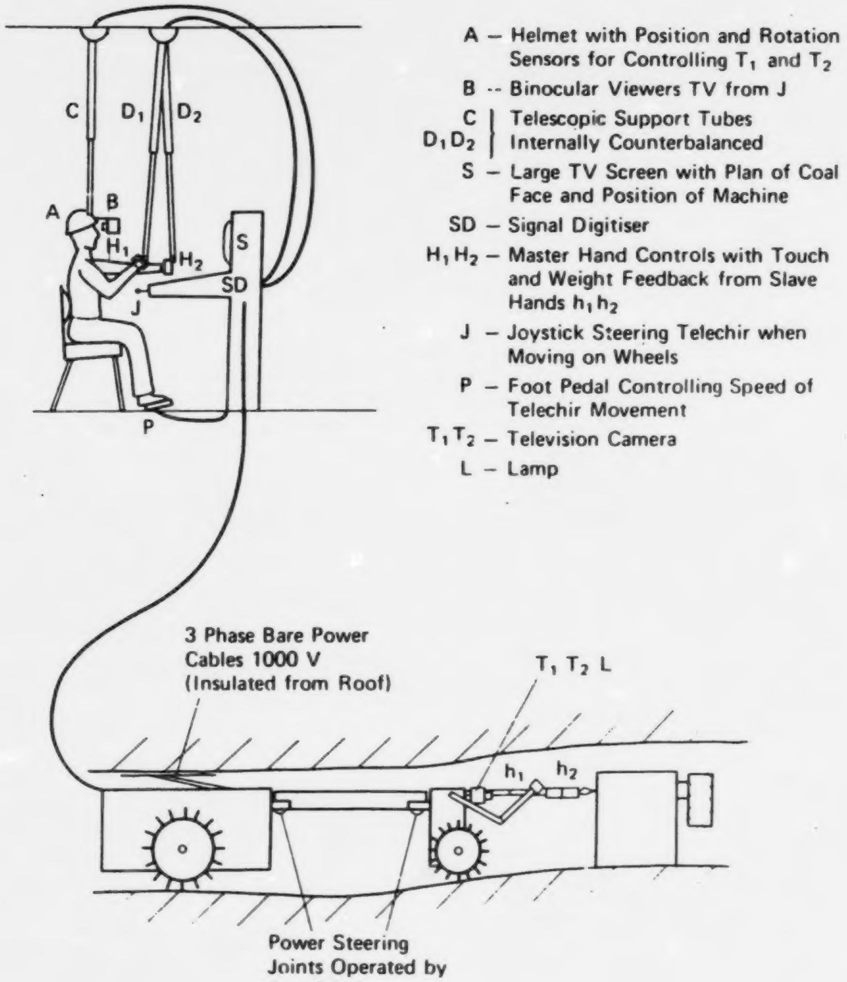

COAL-WATER SLURRY
CLEAN WATER
POWER AND CONTROL CENTRE
OPERATOR
GROUND SURFACE
SHAFT
REAR SECTION
RAMS TO PUSH HOLE FORWARD
FRONT SECTION
COAL TRANSPORTATION SYSTEM PLUS POWER CABLES PLUS CONTROL CABLES
COAL CUTTING SECTION
Y
Y'
MOLE
COAL
MOLE TUNNEL
MULTIPLE MOLE TUNNELS
SECTION Y - Y'
N.T.S

FIGURE 4-24

SCHEMATIC REPRESENTATION OF THE MOLE MINING METHOD CONCEPT


C
D₁
D₂
A
B
H₁
H₂
S
SD
J
P
3 Phase Bare Power Cables 1000 V (Insulated from Roof)
T₁ T₂ L
h₁
h₂
Power Steering Joints Operated by Joystick J

A – Helmet with Position and Rotation Sensors for Controlling T_1 and T_2

B -- Binocular Viewers TV from J

C, $D_1 D_2$ | Telescopic Support Tubes Internally Counterbalanced

S – Large TV Screen with Plan of Coal Face and Position of Machine

SD – Signal Digitiser

$H_1 H_2$ – Master Hand Controls with Touch and Weight Feedback from Slave Hands $h_1 h_2$

J – Joystick Steering Telechir when Moving on Wheels

P – Foot Pedal Controlling Speed of Telechir Movement

$T_1 T_2$ – Television Camera

L – Lamp

FIGURE 4-25 DIAGRAM OF TELECHIRIC MINING

(COURTESY PROF. THRING)

PART 5 - POTENTIAL APPLICATION TO WESTERN CANADA

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5.1 GENERAL

In Part 3, we discussed the range of underground mining properties in western Canada and classified them into four major categories which were each further divided into two sub-categories giving a total of eight possible groupings.

Analysis of the pertinent data from each property resulted in only five categories being necessary to identify the properties on the basis of seam thickness, gradient and property location.

One property, which was representative of that group, was selected for each group. These are summarized in Table 5-1. None of these properties have been worked with the exception of the Coal Valley mine which is an operating surface mine at which a small test mine was developed for a short period in 1982-83.

In assessing which mining method(s) could be applied to these properties, the recognized conventional methods - longwall, shortwall, room and pillar (conventional, continuous miner), and hydraulic mining - have been ignored as they are outside the scope of the Study.

The characteristics of each of the five properties are assessed together with those of the mining developments and concepts described in Part 4, which could be applied to the properties.

5.2 RED DEER PROPERTY (CATEGORY 1A)

This property in the Plains contains numerous seams of almost flat lying coal at moderate depths (100-400 m). The roof strata can vary from friable shale to more massive sandstones which are water bearing. The floor strata generally tends to be soft.

In areas where there is a sufficient thickness of cavable material above the coal, the following systems could be applied with benefit provided some form of continuous haulage could be employed in order to reduce traffic on the soft floor.

1. Rib Pillar Extraction (or Wongawilli)
2. ESA Shortwall

Both systems are capable of high recoveries and good productivities without the high capital cost penalties usually associated with longwall or shortwall mining.

In areas where the sandstones come down to or close to the seam roof and there is doubt about the cavability of the roof strata, a system which controls the lowering of the roof would be preferable. This would have the additional advantage of leaving the water bearing sandstone intact and keeping water out of the mine workings.

The only suitable system appears to be:

1. Yield Pillar system with continuous haulage.

However, since this method has not been previously used under massive sandstones, a more detailed investigation of the geotechnical and mining aspects of both the property conditions and rock and strata behaviour associated with the mining methods, is essential for a more realistic assessment of the suitability of the various mining methods.

Other methods, particularly hydraulic, are unsuited because of soft floor conditions and lack of gradient.

5.3 QUINTETTE-BABCOCK MOUNTAIN PROPERTY (CATEGORY 1B)

The Babcock Mountain underground mining block contains several seams ranging from 2.5 to 5.5 metres in thickness, the gradient ranges from 5 to 16° at depths ranging from 200 to 400 metres. The deposit is disturbed by major faults around the perimeter and there is no reason to suppose that there are not smaller faults in sympathy with the major faults. The upper seam is overlain by a massive sandstone, whilst the lower seams have mixed sandstone/mudstone roof strata.

There is some doubt about the cavability of the sandstone. If it proves to be cavable, then the following methods could be applied.

1. Rib-Pillar Extraction
2. ESA Shortwall
3. Narrow Hydraulic Room and Pillar

If the sandstones prove to have poor caving properties, it is likely that the following could be applied.

1. Yield Pillar Shortwall System

More pertinent data about the location and distribution of the sandstones and conglomerates in the roof, and their rock characteristics and behaviour is need to properly evaluate the potential of these mining methods for the Babcock Mountain underground property.

5.4 COAL VALLEY PROPERTY (CATEGORY 2B)

The underground section of the Coal Valley mine is located in the upper part of the Siltstone seam which averages 3.5 m thick. The seam dips at about 15 degrees.

The roof adjacent to the seam is generally composed of carbonaceous mudstone or coaly shale grading into siltstone, shale and sandstone bands ranging from a few centimetres to several metres in thickness. The floor is composed of carbonaceous siltstones followed by interbedded mudstone, siltstone and sandstone. There is no doubt that the roof strata is suitable for caving and the floor strata is expected to be strong enough for mobile equipment.

The gradient poses problems for mobile equipment mining methods, but several of the methods being considered could be applied. These are:

1. ESA Shortwall System on full gradient. The equipment is already working in East and West Europe in almost identical conditions, and is relatively unaffected by gradient.

2. Narrow Excavation (Non-Hydraulic) mining but with the possibility of hydraulic transport. We do not believe the hydraulic mining methods can be utilized because of the nature of the roof strata. Because of the gradients, it would be necessary to layout the mine with the roadways at an angle to the main dip or strike to reduce the effective gradient to allow mobile equipment to operate to excavate the coal and utilize the same gradients to transport the coal hydraulically.

3. Thin Seam Borehole mining with hydraulic transport of coal is also a possibility, but its application would be dependent on the roof strata behaving in a stable manner.

We do not believe that Rib Pillar Mining can be operated on these gradients, nor since the strata is cavable, do we forsee the need to use the Yielding Pillar System.

5.5 WILLOW CREEK PROPERTY (CATEGORY 3B)

The Willow Creek seams lie at relatively consistent gradients of 34°-37° in the mineable zones. The seams range from 2.4 m to 4.2 m in thickness and from outcrop to below 400 metres below the surface situated on the east limits of a gentle fold in the Willow Creek anticline. The rocks adjacent to the seam are sandstones, shales and mudstones.

At these gradients and seam thicknesses, the only developing mining systems which can be considered to be applicable are:

- ESA Shortwall System;
- Narrow Room and Pillar;
- Hydraulic In-seam Borehole.

The application of any of these methods would require the use of roadheaders for the drivage of development roadways either on strike or across the dip at less than 15°.

5.6 SAXON PROPERTY B.C. (Category 4B)

The underground section of this property is located in the Saxon East Block. The seams range from 5.5 to 9.7 metres in average thickness and dipping from 35° to 60°. The floor and roof strata consist mainly of slightly sandy shale, pure shale and sandstone of moderate thickness, all interbedded over relatively short distances. The rock is well jointed and is suitable for caving.

At these gradients, the only methods which could have application to this property (apart from full hydraulic mining) are the thick seam borehole mining system, and the inseam hydraulic borehole method.

5.7 SUMMARY

It is not within the scope of this study to design mines for the representative properties, and in most cases this would not be possible without having made a detailed geological survey, and without further work being undertaken on rock mechanics and mining aspects of the roof and floor strata behaviour for each method.

Evaluation of the various methods and basic site conditions does, however indicate that certain methods have potential for application to western Canadian conditions which range from cavable to probably non-cavable strata.

Table 5-2 summarizes the potential and indicates that the following methods are worthy of more detailed investigation.

1. ESA Shortwall System
2. Rib Pillar Mining System
3. Yielding Pillar Mining System
4. Narrow Excavation Room & Pillar with or without hydraulic transportation
5. Inseam Hydraulic Borehole Mining

TABLE 5-1

Characteristics of Selected Properties

Category	Property	Seam Thickness	Seam Gradient	Location	Special Features
IA	Red Deer, Alberta	to 3.6 m	1°	Plains	Sandstone above seam, weak floors, water
IB	Babcock Mountain, B.C.	2.5-5.5 m	5°-16°	Mountains	Sandstone above seam
IIB	Coal Valley, Alberta	5-10 m	10°-15°	Foothills	
IIIB	Willow Creek, B.C.	3.6 m	34°-37°	Mountains	Variable Quality
IVB	Saxon, B.C.	2-15 m	10°-45°	Mountains	Strong roof and floor

TABLE 5-2

Mining Methods of Interest

Mining Methods	Property Category				
	1A	1B	2B	3B	4B
Yielding Pillar	x	x			
Rib Pillar*	x	x			
ESA Shortwall	x	x	x	x	
Narrow Room & Pillar		x	x	x	
In-Seam Borehole			x	x	x

*includes Wongawilli System

PART 6 - KNOWLEDGE GAPS

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6.1 INTRODUCTION

In the course of our investigations, we have identified several areas where inadequate or complete lack of data hindered or prevented full investigation of other mining methods or identification of source data.

Our comments have been listed under various subject headings.

6.2 GEOLOGY

We find that there is no published record of general basic data about the various mining properties in western Canada, especially for properties considered to be of underground mining potential.

The basic data made available should include:

- Number of Seams
- Seam Thicknesses
- Seam Gradient
- Coal Quality
- Structural Data
- Immediate Roof Strata Stratigraphy
- Immediate Floor Strata Stratigraphy
- Depth
- Likelihood of Water Inflows

We understand that some work is being done by the Institute of Sedimentary and Petroleum Geology in Calgary on compiling computerized coal data across western Canada, but it is not yet in a form suitable for use by the mine planner or researcher.

6.3 GEOTECHNOLOGY

This is an area where virtually no data is available relating to rock characteristics and potential behaviour under the strata stress conditions imposed by different mining methods. In addition, very little is known about the rock mechanics principles involved in the newly developing methods. Quite often, preliminary understanding comes from initial test mining, rather than the preferential source of model and laboratory investigation leading to the development of basic principles for the initial mine design.

Such data as is available should be collated from around the world and further investigations undertaken, particularly into the Rib Pillar Extraction and Yielding Pillar Mining Systems.

6.4 MINING SYSTEMS

The success of any mining system is dependent amongst other factors on the quality of the supporting or back up systems. It was particularly evident during the investigations that developments were trending towards:

(a) increasing production tonnages in relation to development tonnages;

(b) improving coal clearance by use of continuous haulage systems;

(c) automating or reducing the roof support methods; and

(d) extending the mining height of cutting equipment.

These are all areas that require further investigation.

6.5 MINING RESEARCH ORGANIZATIONS

We have listed in Appendix B the places of learning around the world who were contacted in the course of this study, seeking data about any mining related research work.

In Appendix C, we have also listed the Research Establishments and Mines contacted seeking the same data.

The response in most cases, especially outside North America, was poor.

We found that there is no central reference available for the coal industry listing the research work being carried out around the world. Certain organizations like the IEA publish some data, but we believe that there is a need for a broader more comprehensive listing related to the extension of the economic mining of underground coal.

6.6 MINING DATA

In the course of our literature searches, we used key words to search over computerized data bases.

We had great difficulty in finding some relevant literature, partly because of the key words used by the persons identifying the papers, and partly because many data bases do not cover the full spectrum of mining and mining related technical literature.

There is a need to identify the processes whereby the different data bases classify mining material, to identify the 'mining' journals and other sources covered, and to publish a directory listing the relevant data.

Allied with this work, we believe there is also a need to identify the recent increase in computerized data bases available outside North America. The rest of the industrialized world is at last beginning to catch up with the data base revolution which took place in North America in the 1970's, and has much data available of interest to the western Canadian mining engineer.

6.7 AUTOMATION AND ROBOTICS

Whilst the realistic use of this new technology is several decades in the future, the extensive research and development required to develop a practical mining system suggests that a start should be made in the very near future. There does not appear to be any available summary of worldwide mining automation research and development or usage, or even of related areas of research in other industries. Some summary work has been done on Canadian Robotics Research and Development by the National Research Council (NRCC Report 24470) but this needs extending to cover the international scene.

PART 7 - CONCLUSIONS

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7.0 CONCLUSIONS

The work carried out in this study has resulted in the following conclusions:

1. There are no truly unconventional underground coal mining systems under development and reported in the public domain at the present time.

2. The new developments that are taking place are, more realistically, modifications or adaptions of existing systems, to meet, the specific conditions in specific coalfields.

3. Western Canadian underground coal properties can be classified into a number of categories, currently five, but with a maximum of eight, based on coal seam thickness, gradient and site location data.

4. There are four clear contenders for application to the coal in four of the five categories listed. These are:

    1. Rib Pillar Mining
    2. Yield Pillar Mining
    3. ESA Shortwall Mining
    4. Narrow Excavation Room & Pillar

5. Other methods of somewhat lesser immediate interest include:

    1. Hydraulic Borehole Mining
    2. In the longer term - Remotely Controlled Mining

6. All four major developments require a thorough knowledge of rock mechanics, strata control and the stresses generated by the mining method. This information is not readily available

and requires further research, and the detailed investigation of current uses of these developments.

7. Availability of comprehensive data relating to the geological, geotechnical and mining aspects of underground coal properties in western Canada is very poor.

8. Computer data bases are not yet efficient means of accessing data published in mining and related journals.

9. Progress towards remotely controlled mining operations in underground mines is extremely slow and unlikely to result in meaningfull developments during the remainder of the century.

10. Preliminary work on collating information on automation and robotics for application to coal mining should be initiated.

PART 8 - RECOMMENDATIONS

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8.0 RECOMMENDATIONS

1. More detailed investigations are required into the basic rock mechanics and mining principles enabling the Yield Pillar, Rib Pillar, Narrow Excavation and ESA Shortwall systems to show promise of improvement over conventional systems.

2. Consideration should be given to developing better reference documents relating to geological, geotechnical and mining data for western Canadian mining properties.

3. A study of the developments of mining equipment associated with services 'elsewhere' underground, i.e., away from the production faces, should be undertaken.

4. Some uniformity in the referencing and accessing of data in computer and data bases is required. Further investigation is required to determine how this can be best achieved.

5. A broader, worldwide referencing of current research work associated with the mining of coal is required. A study is required to determine how this can be best achieved.

6. An information data base should be developed to cover worldwide research, development and usage of automation and robotics methods and equipment for application to coal mining.

APPENDIX A

REPORT ON SOUTH AFRICAN VISIT

As part of the investigation into alternative methods of mining coal applicable to mining conditions in western Canada, a visit was made under the Canmet contract to the mines of the SASOL Collieries to observe a new method of mining which had been introduced to these Collieries as an alternative to conventional room and pillar and longwall mining. In addition, a visit was also made to the Chamber of Mines of South Africa to ascertain the current research being carried out into coal mining by that body.

SASOL is a South African company, originally a government corporation but now predominantly privatized, set up to produce oil from coal. The first plant, SASOL One, was built at Sasolburg which is situated some 100 km south of Johannesburg in the Orange Free State. SASOL One receives its coal from the Sigma Colliery which is designed to produce coal at the rate of 6 million tonnes per year from underground workings using conventional room and pillar, longwall and rib pillar operations. Sigma Colliery employs some 2,200 people, supplying sub-bituminous coal with a high ash content of around 35 percent to the SASOL One facility which in turn employs some 2,800 people to produce liquid fuels, petrochemicals, chemical products and industrial gas. Part of the Sigma Colliery's coal supply is delivered to the thermal station which supplies SASOL One with power and steam.

Following the success of Sasol One and the process development which took place, the decision was taken to build the SASOL Two plant at Secunda approximately 200 km southeast of Johannesburg in the Transvaal province. SASOL Two went on-stream in 1980 and a third plant, SASOL Three, also located at Secunda, went on-stream in 1982. The two Secunda SASOL plants are virtually identical and both are much larger than the SASOL One plant which served as their prototype. The two plants at Secunda are supplied by Secunda Collieries which consist of four mines. These are Brandspruit, Middelbult, Twistdraai and Bosjesspruit. These four mines, which are underground mines, employ more than 9,000 people and produce almost 30 million tonnes of coal (equivalent to 55% of the total Canadian output). The Secunda Collieries constitute by far the largest underground coal mining complex in the world and produce about 25 percent of the coal mined in South Africa for internal consumption. The coal at Secunda is sub-bituminous with a much lower ash content than that at Sigma Colliery. Coal from the collieries is supplied to both SASOL Two and Three and their related thermal plants which provide electricity and steam. At full production, the plants consume daily 80,000 tonnes of coal, 26,000 tonnes of oxygen and 160 million litres of water. Both SASOL Two and SASOL Three are exceeding their design capacity, a fact reflected in the increased design capacity of the mines serving them, for example, the Middelbult mine was originally designed to produce 3.3 million tonnes per year and it is now producing 6.6 million tonnes per year.

Of the mines in the SASOL Group, however, visits were made to the Sigma Colliery in Orange Free State and the Middelbult and Brandspruit mines in the Transvaal (Figure 1). A brief report on the visit to each of these mines follows.

MONDAY, JULY 8, 1985 VISIT TO SIGMA COLLIERY, ORANGE FREE STATE, SOUTH AFRICA

The visit to the mine included a brief introduction by mine staff followed by an extended visit underground and further discussions on the surface after the underground visit. The staff involved were: Mr. Phillip Crous, Mine Manager; Mr. Gys van Wyk, Underground Manager; Mr. Willie Vergeer, Section Manager; Mr. Andre Slier, Section Manager; Mr. Freddy Hunter, Section Manager; and Mr. Nielen van der Merwe, Geotechnical Engineer. The Sigma Colliery (Figure 1) has a design capacity of 6.3 million tonnes per year and in 1985 is expected to produce some 5.9 million tonnes per year. The reason for the reduction in 1985 capacity is a reduction in the sales of industrial gas from the SASOL One plant which leads to a reduction in the demand for coal from the mine. The mine employs some 2,200 people, of whom 200 are white and 2,000 are black. The mine needs approximately 1,800 people to operate but carries the extra staff on the books to cover absenteeism. About 85 percent of the labour force come from the homelands and generally return home for a four month period after each year's work. The mine, in endeavouring to reduce this absenteeism and particularly the loss of skilled people, by trying to persuade this black labour force to take a year's contract, which allows them 36 days leave during that year.

Sigma is mining three seams (Figure 2) which range from 90 to 190 m deep. The mine permit area covering this is 16 km in one direction and 8 km in another. The seams are relatively close to each other as shown on the attached figure. In the older areas of the mine, the numbers 2A and 2B seams are mined and they are now considering whether it is possible to mine the number 3 seams over the top of the original workings. Elsewhere in the mine, number 3 seam is being mined with seams 2A and 2B to be mined later. The strata above number 3 seam comprises about 4 m of weak shale mudstone followed by massive sandstones and above the sandstones a massive dolorite sill. It is a sub-bituminous coal with a high ash content (25 percent) and is extremely hard. A major problem geologically is the presence of numerous dolerite sills and dykes within the coal seam which cause burning of the coal adjacent to the inclusions. The mine started production in 1951 and between 1951 and 1982 produced over 100 million tonnes of coal. The mine has some 240 million tonnes of coal in reserve which is expected to see out the working life of the SASOL One plant.

The mine operates a three shift system, the men working 9½ hours per shift, which allows one hour per travel, half an hour for shift preparation and mealtime with eight hours working time per shift on the job. Crews take over on the job and therefore maintain continuous operation of the equipment.

The mine production comes from longwall (27 percent), producing 1.59 million tonnes in the year, averaging 1,800 tonnes per shift. Continuous miners on rib pillar extraction and longwall development are responsible for 37 percent of the output at 2.9 million tonnes whilst conventional room and pillar using drill and blast methods is responsible for 36 percent of the output at 2.12 million tonnes. The drill and blast room and pillar operations are expected to produce on average 1,200 tonnes per shift. The number 3 seam, which is the main seam being worked, has a Hardgrove figure of almost 80 and contains between 30 and 35 percent ash. The coal from the mine is delivered to SASOL One and the power station. All +6 mm coal, some 3.54 million tonnes per year, is delivered to SASOL One whereas all -6 mm coal is delivered to the thermal station, i.e. 2.36 million tonnes per year. The mine has a major problem in that it is producing more fine coal than the power station can burn and cannot produce enough of the +6 mm coal to meet Sasol's total requirements.

Development for main roads in the mine consists of seven entry systems driven on 24 m centers, i.e. 18 m square pillars with 6 m wide roadways. The roof is supported by four 1.8 m resin rockbolts, the outer bolt set not greater than 0.5 m from the side of the roadway, the remainder equally spaced in between, with 2.5 m between rows. In the future they will be testing angled bolts over the side of the roadways for additional security.

The visit underground was made to a rib pillar mining section and also to a conventional drill blast mining section. The rib pillar layouts are shown in the accompanying Figure 3, essentially this is the development of a four entry primary system off which is driven a three entry secondary development with a two entry tertiary development at the end of the 200 m long panel parallel to the primary entry and designed for leakage ventilation. All roadways are on 24 m centers with 6 m wide roadways and 18 m square pillars designed in accordance with Professor Salamon's recent theories on pillar design under strong sandstone and dolerite conditions. The panel in which the rib pillar mining takes place is 48 m wide, giving a total of 96 m including the secondary development which is retreated back during the pillar mining. The average production from development by continuous miners when opening out the rib pillar section is approximately 900 tonnes per shift and this rises to 1,200 tonnes per shift in rib pillar production when the block is being mined out. Particular care has to be taken in the mining to ensure that the machines cut to a specific horizon or their roof conditions deteriorate considerably. In addition, they have learned by hard experience that they must get the sandstone and dolerite cave or else they suffer severe weights. The caving front is maintained on a distance greater than the critical width or length. The sequence of operations when the rib pillar is mined is shown on the accompanying Figure 4 but comprises the miner driving across from the belt roadway, leaving a pillar some 6 m wide parallel to the secondary development and adjacent to the goaf. When this roadway has been driven 6 m wide, rockbolted with 3 bolts per row, the miner then proceeds to remove the rib pillar by a series of angled cuts, a wooden breaking off line being maintained to provide safety for the operator. South African regulations permit the machine to advance 12 m without support. This therefore ensures that the miner can remove the rib pillar without the need for support in that area. They have found that the rib pillar production is reduced because of the time required to set the two rows of timber for the breaking off support. They are watching with interest the work that is being done at Middelbult mine where trials are currently taking place with the use of mobile power supports in place of the timber.

The rib pillar operations are undertaken using Jeffrey H2 hard coal miners, two Torkar 14-ton cable reel shuttle cars, a rock bolting machine and a feederbreaker kept with two pillar lengths of the face. The operating team comprises 14 people including artisans or mechanical/electrical staff and consists of 1 continuous miner operator, 1 cable handler, 2 on the rock bolting machine, 4 on shuttlecars, 4 handling the breaking off line timbers, 1 general labourer and 3 artisan electromechanics. In addition, there is 1 black team leader and 1 white miner responsible for the section.

In the conventional drill blast room and pillar operations, between 900 and 1,300 tonnes are produced per shift from 13 working faces on a 7 entry system. The roadways are 24 m centers, 6 m wide giving 18 m square pillars. The equipment in this section consists of 2 coal cutters, 2 gathering arm loaders, 2 shuttlecars, 2 rock bolters and a number of hand-held electric drills. A feederbreaker is used to deliver the coal from the shuttlecars onto the conveyor and this is maintained within two pillar blocks of the working line.

The section is manned by a crew of 29 comprising 1 white miner, 24 black miners, 1 white electromechanic and 3 black electromechanics. Twelve faces are normally fired and loaded per shift with the depth of cut with the coal cutter at 2.5 m resulting in an advance of 2.2 m. Support is provided by full column resin bolts 1.8 m long which have to be set within 1.8 m of the face. In poor conditions, in addition to rock bolts, flat bars, W-bars or a special compound bar are utilized to improve roof conditions.

Like most of the mines in South Africa, they are running into difficulties with the maintenance of their equipment, particularly continuous miners, troubles relating mainly to hydraulics and electrics and as a result of this, the availabilities of the machines are not as high as they should be and the costs are also higher because of the poor availability and the higher maintenance costs.

At the Sigma Colliery, the costs per tonne, which do not include depreciation, was stated to be as follows (in U.S. Dollars):

- conventional drill and blast room and pillar - $2.01

- development by continuous miner for longwall, two entry - $4.44

- rib pillar development by continuous miner - $3.54

- room and pillar conventional depillaring - $1.09

- longwall production - $1.82

- rib pillar production - $2.53

The rib pillar production cost is considered high for the reasons stated above, mainly high maintenance on the continuous miners.

Thirty-five percent of the output of the mine is less than 6 mm and surprisingly the longwall produces more large coal, i.e. +6 mm, than the continuous miner room and pillar operations.

The mining conditions underground were extremely good. The mine was spotlessly clean, extremely well stone dusted with pillar sides remaining as formed due to the extremely hard nature of the coal. Materials underground are transported by containerization using an Eimco or Toro LHD vehicle. These also carry containers specially adapted for men, and secondly by tractor trailer units or standard LHDs. They also have many specialized containers or pallets.

The staff use Toyota Landrovers with flameproof diesels and these are allowed to within 200 m of the working face. In addition, surprisingly, there are also a considerable number of bicycles in use underground. A good portion of the main roadways are lit by standard commercial lights rather than flameproof or intrinsically safe lighting.

Although the longwall section was not visited at this mine since arrangements have been made to see the world record face at

Brandspruit Colliery, the comment was made that the longwall face provides excellent production with its 13 man crew which includes electromechanics and is considered to be equivalent to three continuous miner sections. They do, however, have a number of problems with the longwall, in particular associated with the loss of production during the movement of the longwall face since they only have one, secondly, its flexibility, or lack of, in dealing with the innumerable sills and dykes which intrude into the coal and thirdly, coping with the high capital depreciation. The three factors were instrumental in their search for and their development of a more flexible, less capital intensive, system which could utilize their continuous miners and which led to the development of the rib pillar operations. The result of these changes is that 37 percent of their output now comes from rib pillar operations, 27 percent from longwall and 36 percent from conventional drill and blast room and pillar operations.

Finally, the mine have recently appointed a geotechnical engineer to assist them with the interpretation of the strata control requirements of the rib pillar operations in order to try and develop the rib pillar system even further. A general comment about caving is that they need to expose an area equivalent to the depth squared before they obtain their first cave and that their experiments to date have shown that the best results are obtained when the length of the rib pillar or longwall panel are greater than the critical width for maximum subsidence.

TUESDAY, JULY 9, 1985 BRANDSPRUIT COLLIERY

This mine is located within the SASOL Two-Three complex and is subject to a considerable amount of security. The mine is one of four mines in the Secunda Collieries Group (Figure 5). The Brandspruit mine is producing just under 9 million tonnes per year from the number 4 seam which is 3 m thick and overlain by sandstone some 7 m thick, underlain by massive sandstone up to 75 m thick. The coal is situated some 175 m below the surface and is overlain closer to the surface by a number of dolorite sills ranging from 10 to 45 m in thickness (Figure 6).

The mine employs some 1,600 people of which 200 are white. The mine that was originally designed to produce 6 million tonnes per year is scheduled to produce 8.2 million tonnes per year in 1985.

The mine operates three longwall and three conventional room and pillar sections. The coal is a sub-bituminous coal containing between 18 and 20 percent ash with very high hardgrove numbers which is perhaps indicated in the pick consumption which runs at 8 tonnes per pick whereas you would normally expect 30 tonnes per pick in average American conditions.

The longwall can cut up to maximum of 3.2 m in height and in certain areas of the mine where the seam increases above that height coal has to be left in the top. The mine is managed by a General Manager who is helped by a Mine Manager, an Underground Manager and three assistant Underground Managers. A visit was made underground with Mr. John Collins, Assistant Underground Manager, responsible for one of the two producing areas of the mine, and it was in his section that the longwall was operating which holds the current world record of some 210,000 tonnes of coal in a month. The mine works a three shift system which allows 8 hours underground at the face with takeover on face. The mine produces on average 170,000 tonnes per week of which 50 percent comes from the three longwalls which work 17 shifts a week, 30 percent from four conventional room and pillar operations which work 11 shifts per week and 20 percent from four continuous miners operating 17 shifts per week on longwall development, four miners and one miner working rib pillar and pillar extraction.

The longwall face is 200 m long (Figure 7) and is operated by an Anderson-Strathclyde AM1000 DERDS Shearer with 420 tonne Klockner shields and Mining Supplies twin centre strand 26 mm AFC and stage loader with the transfer from AFC to stage loader being by side discharge.

The face crew comprises 15 people namely 1 white miner, 1 black bossboy, 2 shearer operators (one at each end), 1 cable man, 6 on supports plus 1 black boss boy, 1 on the stage loader and 2 on cleanup. In addition, there are 2 artisans, 1 electrical and 1 mechanical assisted by 4 boys. The roof caves well and immediately behind the supports although somewhat blockily. The longwalls initially were oriented in a north-south direction along face but later these were turned to east-west as they were found to be better for cutting. The relationship to the cleat and joint direction is not yet known and this is in fact one of the areas that the new geotechnical engineer to the SASOL Group will be investigating.

Working conditions on the face were superb. Although there was plenty of water everywhere, the presence of a sandstone floor did not cause any traction or support problems. The machine was cutting at some nine metres per minute with little dust although the coal is in fact very hard. The coal from the face delivers onto a very short stage loader with no overlap, being attached directly to the tailpiece of the panel belt conveyor. The conveyor is fitted with an automatic loop takeup and this eliminates the need for any overlap with the stage loader.

The first weight and cave occurs after 90 m of advance (seam 170 m deep) and under normal working conditions the coal in the face cut by the shearer is under sufficient abutment pressure that it is constantly working and assisting the cutting machine. This probably accounts for the speed at which the machine cuts in the hard coal and the lack of dust.

The longwall operator on the face is the highest paid of the black labour force (with the exception of the two boss boys) and earns between 19 and 20 Rand per day, approximately $14 per day, with the ability to earn up to 5 percent as a production bonus which is paid weekly.

Longwall development was originally attempted as a two entry system with 45° crosscuts and has now been extended to a three entry system with roadways on 18 m centres and 45° crosscuts. The reason for this is that a two entry system was found to be very low in production for a continuous miner in that it did not have sufficient working faces to enable the machine to remain in production. The latest development in the three entry system is that the pillars between one of the entries has now been put on 100 m centres for crosscuts instead of 50 m as was original (see Figure 7). Longwall development is capable of producing in excess of 4,500 tonnes per week.

Conventional continuous miner room and pillar sections were first operated by Joy 12CM continuous miners supported by Joy 12SC shuttlecars and rockbolting machines. The Joy 12CM is only capable of producing about 8,000 tonnes per week and they have recently introduced the Joy 12HM9 (which is the miner developed for cutting potash) and this is capable of producing up to 12,000 tonnes per week. The 6 m roadways are supported by three bolts 2 m long, with pillars on 24 m centres. The coal has a hardness of between 20 and 30 Mpa, the sandstones having a hardness of approximately 250 Mpa.

The crew operating the continuous miner comprises 11 men, 1 continuous miner operator, 1 cable handler, 2 on shuttlecars, 2 on rockbolters, 1 on the feederbreaker, 2 on ventilation, 1 white miner and 1 black boss boy. In addition, there is 1 artisan electromechanic assisted by 2 black boys.

No costs were available from the Brandspruit Colliery although in terms of ratios, conventional drill/blast coal was classed as being

100, the cost of room and pillar operated by continuous miners varied between 102 and 105 and longwall including longwall development being around 102.

WEDNESDAY, JULY 10, MIDDELBULT COLLIERY

This mine was also within the SASOL Two-Three security complex and was originally designed to produce some 3.3 million tonnes per year. It has been expanded and is now producing some 6.6 million tonnes per year. The main reason for the ability to expand was the fact that the main drift into the mine, which is some 100 to 120 m deep, was designed and equipped with two belt conveyors. In the original design they were intended to work with one operational and one standby. Both are now operating to their design capacities. The mine employs some 2,200 people of which 260 are white and 1,940 are black.

The mine has a take of approximately 4.5 km by 4.5 km and is working the number 4 seam which averages about 3.7 m thickness but does vary up to 5 m in thickness (Figure 8).

The mine is worked entirely with room and pillar or rib pillar operations. In fact, in March 1984, it obtained the South African national record of 121,000 tonnes per month with a continuous miner. During that particular month, the miner section was manned by an average of 19 employees, advanced a maximum of 107 m in a shift, averaged 4.5 tonnes per minute over the month and the maximum output achieved in one week of room and pillar and rib pillar depillaring was 25,600 tonnes with a 67 percent availability.

At the visit to mine, I was welcomed by Mr. J.C. van Rooyen, Mine Manager, Mr. Peter van Zyl, Resident Engineer, Mr. Johan Cloete, Mine Captain and Mr. Willie Uys, Section Captain. Following brief discussions on the surface, an extensive underground tour was made looking particularly at the rib pillar operations and the conventional room and pillar operations.

The mine produces 65 percent of its output from rib pillar operations with the remainder from conventional room and pillar using LHD machines instead of gathering arm loaders and shuttlecars. On average, the continuous miners produced just under 14,000 tonnes per week in 17 shifts but when they are on pure extraction this rate can go up to around 25,000 tonnes per week. Main entry development is on seven or nine entries at 24 m centers. The crews in the rib pillar operations comprise 1 white miner, 1 black team leader, 1 continuous miner operator with 2 cable handlers, 3 shuttlecars, 2 on rockbolts, 1 on the feederbreaker and 4 general labour responsible for setting timber, moving ventilation ducting and general work.

The development of the rib pillar panels is essentially the same as that at Sigma with four entry primary development, three entry secondary development and two entry tertiary or ventilation development (Figure 9). The length of the panels varies from 108 to 216 m but at Middelbult they are experimenting with lengthening the rib pillar from the standard 48 m at Sigma to 72 m and widening out the three entry development from 24 m centers to 36 m centres. The idea being to reduce the amount of development which is less productive and increase the amount of rib pillar extraction which is more productive. Previously they have successfully worked at the same dimensions as Sigma, but are currently developing their first panels at the larger dimensions. Moving from 24 m to 36 m centers actually increases the safety factor in their pillars from 1.6, which is the standard design, to in excess of 2. The rib pillar is mined in the same manner to a width of 6 m and they believe that the rib pillar has to be between the abutments which vary from 7 to 17 m from the solid coal.

The rib pillar operations at Middelbult are being used to try two new developments for South African rib pillar and room and pillar operations. The first is the use of Voest Alpine mobile breaker shields using four per section as per the attached sketch (Figure 10). These comprise a standard four leg powered shield with a 100 tonne setting load and a 500 tonne yield load mounted on crawlers and equipped with its own power pack and capable of remote operation. These units have a closed height of 2.2 m and a maximum height of 4.2 m and have been in use for approximately 2 months. The general benefits to the mine are that it reduces the labour force required for timbering, it speeds up the operation of the continuous miner which does not have to stop whilst timber breaking off lines are set and as a result they believe that production and productivity will increase by between 10 and 15 percent. Powered supports are also particularly helpful in dealing with the sandstone roof which normally caves well but in large lumps. The mining operations result in about 1.5 m of subsidence on the surface from the 3.5 m seam extraction. The second innovation being tried at Middelbult is the use of continuous haulage by means of a Joy Serpentix monorail mounted bridge conveyor behind the continuous miner. This unit is some 142 m long driven by head end and tail end drive pulleys with three intermediate monorail drives to move the conveyor. The system of operations is that the continuous miner feeds direct into a Joy bunker car which is equipped with two rockbolting units. The roadway is supported by two mechanical rockbolts 1.5 m long at the sides and a center bolt which is fully bonded resin to enable the Serpentix conveyor to be suspended from it. The continuous miner delivers direct onto the bunker car which in turn delivers via a 9 m bridge conveyor onto the Joy Serpentix conveyor (Figure 11). This bunker car contains a breaker which reduces the lumps before they are delivered onto the mobile conveyor. The lump size produced during rib pillar extraction is too large to be handled by the Serpentix conveyor.

Whilst the mine is still having some problems with this conveyor, particularly in learning how to handle and control it, they estimate that it will result in a further 10 percent increase in production and productivity. They have two main concerns with the unit.

One is that with any alteration of direction at a junction it is necessary to physically dismantle the monorail and rebuild in the line of the new direction it is intended the unit should go, i.e. some form of monorail track point has not yet been developed. The second concerns the delivery onto the panel conveyor at junctions.

The other unusual feature underground at this mine is that they have built a 3,000 tonne inseam bunker 16 m in diametre to accommodate surges from the rib pillar operations and also to enable the working faces to continue operations for small delays outbye the mine. The coal is brought to the surface through two belts up the inclined drift whilst men and the underground supply of materials are lowered down through a large diametre shaft operated by a six rope Koepe winder in double purchase. This winder is capable of handling equipment 9 m long by 5 m wide and, weighing 40 tonnes under automatic control, or under manual control, 50 tonnes. This means that most of the pieces of equipment can be taken underground without dismantling, a significant saving in time and manpower for getting equipment underground and to work. In addition to this large cage and counterweight hoist, there is an automatic 12 man Otis Lift which operate from surface to the underground levels.

The four mines in the SASOL Two-Three complex deliver their coal to a central storage area. Each mine has a 12,000 tonne raw coal storage at the top of the slope from underground and the mines feed in pairs to two 500,000 tonne raw coal stockpiles which are maintained adjacent to the SASOL Two and Three plants. This is partially to blend coal and also to provide some flexibility for the plants and for the mines. The one million tonne stockpile works out at about 10 days supply for the SASOL plants. Finally, in summary, it is pertinent to comment on the size and efficiency of the operations of these mines. The surfaces are spotless, the underground workings are tidy and efficiently laid out and although the manpower is obviously considerably cheaper than Canadian manpower and they do utilize larger numbers of people, perhaps one-third more than North American standards, the productivities (output per manshift) are often in excess of those achieved in North America. The accompanying table lists the production levels from the four mines in the Secunda Group for March and April 1985 together with the consumptions by SASOL Two and SASOL Three for those months. It should be noted that SASOL Three is still undergoing debottlenecking and this was the result of the fall back in coal demand for April. The record production from the four Secunda Collieries in one month was in March 1985 at 631,395 tonnes from the four mines and the record consumption by SASOL was in February 1985 when SASOL Two consumed 313,485 tonnes of coal and SASOL Three 311,430 tonnes of coal. In addition, the maximum tonnages produced by the four mines at various stages of their life are shown also on the accompanying table. One final comment on the security at these plants, the SASOL plants produce about 75 percent of South Africa's requirements for oil and oil-based petrochemicals and have been in the past targets for guerilla attacks, in fact both SASOL One and SASOL Two have been attacked. Security at the plants and at the mines is intense and it was neither possible to take photographs nor was it feasible to bring away plans of the underground operations. The report, therefore, is not supported in the normal manner with the usual plans of mines visited. However, the hospitality and information made available otherwise by the mine staff was superb.

THURSDAY, JULY 11, 1985 VISIT TO EDWARD L. BATEMAN, BOKSBURG, JOHANNESBURG, ONE OF SOUTH AFRICA'S LEADING FIRMS OF CONSULTING ENGINEERS IN COAL, GOLD AND DIAMOND MINING

A visit was made to obtain information about the South African coal industry and its potential. The South African coal industry is generally aimed at three markets, namely that of power generation, conversion of coal to oil and exports. In 1981 some 98 million tonnes of coal were produced in South Africa of which 54 million were used for power generation, some 30 million for export, approximately 12 million for synthetic fuels, 8 million for metallurgical use and approximately

TABLE 1

Production (Seconda Collieries) and Usage (SASOL 2 & 3)

	(tonnes of coal)		
	March '85	April '85	Record
Seconda Collieres - (Record Month - 631,395t - March '85)			
Bosjesspruit mine	155,010	121,900	159,279
Brandespruit Mine	187,036	141,900	187,036
Twistdraai Mine	159,141	123,600	159,141
Middelbult Mine	130,208	105,400	140,406
SASOL Plant - (Record Month - 624,915t - February '85)			
SASOL 2	-	-	313,485
SASOL 3	-	-	311,430

25 million for commercial use. In 1985 the expected demands are 66 million for power generation, 40 million for synthetic fuels, 26 million for commercial, 11 million for metallurgical use and 37 million for export, giving a total of 180 million tonnes. The forecasts for 1990 and the year 2000 are for total coal production to be 253 million and 375 million tonnes respectively.

It can be seen that the South African coal industry is expected to expand considerably over the next few years and in fact between 1985 and 1990 it is anticipated that some $5 billion will be spent on the coal industry. Some of this will be spent on new mines, some on expanding existing mines and some on the Phase III and Phase IV expansions of Richard's Bay Export Terminal.

The major mining companies producing coal in South Africa are Anglo-American Coal Corporation (Amcoal) which produces about 45 million tonnes per year, General Mining Union Corporation (Gencorp) which is producing some 35 million tonnes per year, Sasol which is currently producing around 36 million tonnes per year and Rand Mines.

The latest figures available for the South African industry relate to the 1984 year when the industry produced 159 million tonnes, 155 bituminous and 4 million anthracite. Coal provides approximately 75 percent of South Africa's energy requirements. In 1983, 42 percent of the coal production was used to generate electricity, 28 percent in coal liquefaction and 21 percent was exported. In fact, coal is South Africa's second largest earner of foreign exchange after gold. Insitu reserves in South Africa are said to be in excess of 110 billion tonnes of which 51 billion are regarded as recoverable by current economic mining methods. This reserve is based on a mineable thickness ranging from 1.2 to 6 m and to a maximum depth of 300 m.

The latest figures for mining methods used in South Africa relate to the year 1981 when 33.7 percent was produced from open cast mines, 51.3 percent from mechanized bord and pillar mining, 8.9 percent from bord and pillar using continuous miners, 2.3 percent from pillar extraction and 3.8 percent from longwall. Since that time, however, there has been a considerable increase in the number of longwall faces and rib pillar extraction systems at the expense of both the mechanized (drill and blast) and continuous miner bord and pillar operations.

I am indebted to Mr. Roger Falls, Managing Director and Dr. Paul White, Manager, Consulting Division, of Van Eck and Lurie, a division of Edward Bateman, for providing these figures.

FRIDAY, JULY 13 VISIT TO THE CHAMBER OF MINES OF SOUTH AFRICA, JOHANNESBURG

A meeting was arranged with Dr. Horst Wagner, Research Associate of the Chamber of Mines, who with other members of his staff provided me with details of the operations of the Chamber and of the current research work that they are undertaking.

The Chamber of Mines is a private company, with no connection with any government agency, which provides legal, technical, industrial relations, research, insurance, medical and labour resources (recruiting) services to its member companies. It is primarily concerned with gold and coal operations. The coal industry employs some 70,000 people, produces approximately 150 million tonnes per year, whereas the gold industry employs 500,000 people and hoists 100 million tonnes per year of rock.

The Chamber undertakes negotiations on behalf of industry with the new miners' union and carries out a considerable amount of research as guided by the research committee run by members of the Chamber. The research program is engineered around the major problems identified by industry as affecting their long-term profitability. This profitability is defined as the efficient and economic use of reserves, the reduction of costs and the ability to mine safely.

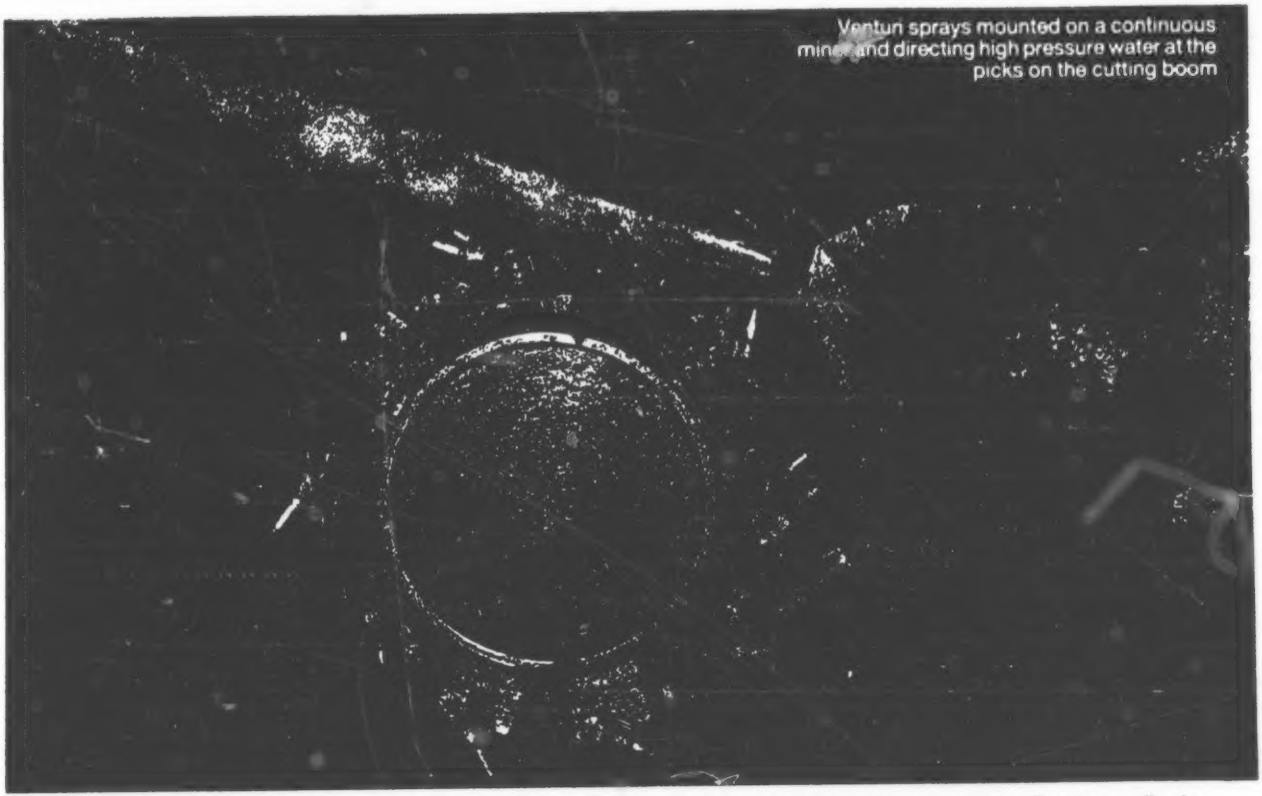
The Chamber has an annual budget of some $20 million dollars of which 95 percent is spent on the gold industry and 5 percent on the coal industry. The Chamber has six laboratories, five related to gold and one to coal, and six branches which service the laboratories covering the administration of professional services, engineering materials, engineering services, engineering systems, environmental engineering, industrial hygiene and mining. The six laboratories include coal mining, gold exploitation, environmental engineering, human resources, rock mechanics and stoping technology.

In the coal mining area, the problems that are being investigated by the Chamber of Mines include in the environmental field, the question of dust suppression particularly in view of the hard coals to be found in South Africa and also in the use of self rescuers. Mining problems being investigated relate to mining equipment data bank, mining methods which are a further attempt to improve the efficiency of coal production, the evaluation of the performance characteristics of continuous miners and in the coal cutting field in particular with water jet assisted cutting. In the strata control area, the program of work is directed largely at collecting information which will lead to a better understanding of ground movements around total extraction tunnels and on the strength of coal pillars. In relation to mine design, investigations are being made into longwall mining performance, rib pillar mining performance and the protection of surface structures. In pillar design a considerable amount of work is being done in the design of coal pillars as workings in South Africa tend to become deeper, particularly by their own standards. A summary of the 1984 annual report dealing with coal research is given at the end of this report.

Of particular interest is the work being carried out at New Denmark Colliery where the first attempt to mine 6 m in one lift is being undertaken using an Alpine AM100 miner working in the rib pillar extraction system. At the opposite end of the scale at Kilbarton Colliery in Natal, an attempt is being made to mine a 0.8 m seam using yielding pillars whilst at Matla Colliery a longwall is to be operated at a depth of only 50 m with a targeted production of 10 million tonnes per year. At Greenside Colliery, work is also being done on rib pillar extraction in 6 m and in recording and evaluating performance characteristics of rib pillar, conventional drill blast room and pillar and continuous miner room and pillar. The general comments were that conventional room and pillar were still capable of regularly producing 120,000 tonnes per month and that the problems under investigation related to the availability and maintenance of continuous miners and on the use of continuous haulage in an effort to improve the performance levels of continuous miner operations and thus reduced the need to use explosives underground. At Longridge Colliery, rib pillar operations are to be attempted at depths in excess of 250 m. For this purpose, pillar safety factors have been increased from 1.6 to 2.4, pillars being on 35 m centers with 5 m wide roadways in 2 m thick seams.

In summary, the major activities in coal mining in the Chamber of Mines are to promote and control research which will lead to greater productivities and performance from their existing systems, i.e. the continuous miner type systems, since in many of the coalfields the presence of dolerite dykes and sills often prevents the more widespread application of the longwall mining method.

Chamber of Mines of South Africa
Research Organization
Annual Report 1984



Venturi sprays mounted on a continuous miner and directing high pressure water at the picks on the cutting boom

Compared to the research for gold mining, the Research Organization's coal mining research effort is smaller in scale and focuses on those aspects which are specific to the South African coal mining industry.

The programme of work is designed around three specific problem areas, Environment, Mining and Strata Control. Investigations within the **environment problem** relate mainly to safety and health, while work on the **mining problem** is concerned with the efficiency of mining equipment and systems. Aspects covered by the **strata control problem** area include safety, as in the control of ground movements of underground workings, and efficiency, which is defined as the better utilization of coal reserves.

ENVIRONMENTAL PROBLEM

The increased use of mechanized coal cutting machines, the greater mining depths and a wider application of total extraction mining methods have emphasized the importance of alleviating the problems associated with airborne dust, emission of methane and spontaneous combustion.

Dust Suppression

The basic objective of the work in this area is to develop more effective means of dust suppression on coal cutting machines, either by adapting existing systems or by developing new ones. Work continued on the development and testing of dust allaying systems for continuous miners and testing procedures were devised to quantify more accurately the magnitude of the benefits to be gained through adopting new systems.

It was found that the combination of venturi sprays and water-powered dust scrubbers offers great potential for reducing the dust hazard at a relatively low cost. However, to be effective higher water pressures than used normally are required. As a result water systems with pressures of around 5 MPa have been introduced using both 'on-board' and 'off-board' mounted pumps.

Research on improving the efficiency and reliability of the pressurized water

Model of water-powered scrubber showing the mechanism of water sprays within tubes creating air flows systems is continuing.

Providing adequate clean water to the working faces has been identified as a particular problem at some of the collieries using continuous miners. Therefore, mine water reticulation systems are being studied to determine the weaknesses of existing systems and obtain the necessary pressures and flow rates at outlets.

Self-Rescuers

Loss of life in colliery disasters over the last few years has emphasized the need for greater protection of underground workers. Priority was, as a result, given to a feasibility study into the use of self-rescuers in South African collieries.

Self-rescue equipment predominantly in use overseas is the filter type which provides protection when there is sufficient oxygen in the atmosphere for life-support. Six incidents which occurred in South African collieries over a number of years were analysed and the life-saving potential of various self-rescuer systems evaluated. It was established that under local South African conditions a self-contained self-rescuer worn on a belt would provide the most effective protection.

Self-contained, oxygen-based self-rescuers are now being designed and developed specifically for local requirements by manufacturers working in close liaison with the Research Organization. Work is now being devoted to the preparation of guidelines to establish disaster survival facilities based on these self-rescuer units.

MINING PROBLEM

The growth of coal mining in the past few years has seen a parallel increase in the equipment used and in the diversification of extraction methods. Because of the high capital cost of modern coal mining equipment it is important to be able to quantify the expected performance of a mining system under given conditions. Work in this problem area is, as a result, aimed at collecting and analysing the necessary information on types of equipment, mining methods and coal strata characteristics.

SELECTION

The research is currently aimed at evolving procedures for selecting mining methods and equipment using economic and technical criteria.

Mine Equipment Data Bank

A computer based data system is being established which will contain the relevant manufacturer's technical specifications on available mining equipment as well as field performance data to assist mines in equipment selection.

Mining Methods

In an attempt to further improve the efficiency of coal production, existing methods of underground extraction were reviewed and their performance compared in relation to different physical and operating criteria.

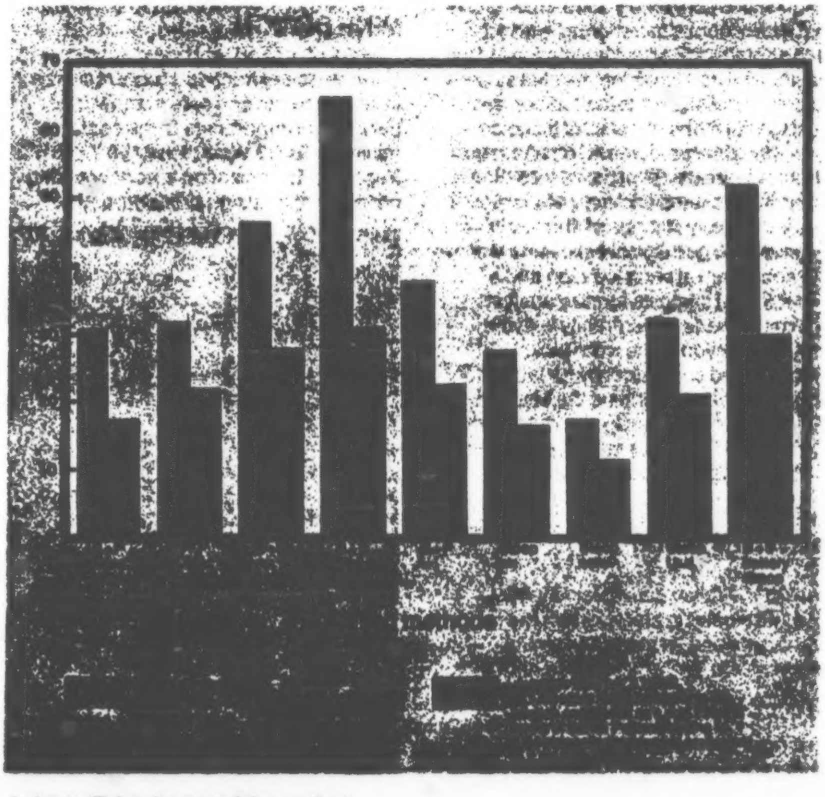
A survey by means of a questionnaire and underground visits was conducted and then followed up by a detailed study of the more important mining methods. Seventeen collieries were involved and 34 sections and nine different methods of pillar development and pillar extraction were covered. Because of the many extraneous factors which affect underground production, it was found that establishing a truly representative result for each method was impractical. However, certain areas of the study were significant, showing that some methods cost more in terms of capital expenditure per annual ton of production than others and that labour productivity varied significantly between methods used.

A predictive model based on the study and related to certain physical and operating parameters is being constructed.

Evaluating the Performance Characteristics of Continuous Miners

The monthly performance of all continuous miners continued to be monitored. A computer data base for monitoring the performance of longwall panels was completed during 1984. Analysis of information in the continuous miner data base identified various relationships between different levels of production. For example, a distinct relationship exists between the production per operating hour and production per total hour. In addition, there is no marked difference in the ratio of these two production rates (which is equivalent to machine availability) for various mines and machines. It appears therefore that variations in the rate of production between different mining situations are not caused by machine availability, but by the method of utilization of the equipment.

An instrument for measuring the



Labour efficiencies per mining method

speed at which a production continuous miner cuts into the coal during sumping has been developed for further studies of production rates. This speed is known as the sumping speed and the instrument which measures variations in speed during a single sump and between successive sumps, as a sumpmeter. Preliminary indications are that the production rate of a continuous miner taken while the machine is actually cutting coal is 10 times the average production rate assessed over a full shift. This suggests that significant improvements are possible by addressing the questions of low machine and system utilization between the point of actual coal production, the cutting head, and, for example, a surface stockpile.

COAL CUTTING

Data from field and laboratory investigations are being collected for research into improving the performance of coal cutting machinery. A method of predicting the performance of a machine and its ability to cut a seam given certain physical and chemical parameters is also under investigation.

Pick Wear

Underground tests were started to investigate pick wear particularly with regard to determining the progression from new to completely worn. During one test a continuous miner drum is laced with new picks. Particular attention is being given to identifying the characteristics of the pick and its location on the cutting drum. The duration of the tests is according to a predetermined number of shuttle car loads. Each pick's loss of mass is measured and the wear is graded visually in terms of change in geometry. A geological assessment of the coal seam at each location and a collection of samples for size analysis are being made concurrently with the trial. A selection of the worn picks will also be used subsequently for laboratory experiments to determine the effect of the degree of pick wear on cutting forces and specific energies as well as size distribution of the coal product.

Assisted Cutting

A 30 kW rotary cutting facility was commissioned in the laborarory to research water jet assisted cutting, methane ignitions and the optimum cutting conditions in coal and sandstone. The machine simulates the single pick cutting action of continuous miners and shearers in full scale experiments using coal blocks with a mass of up to 2 000 kg. The preliminary results indicate important benefits can be gained from both the use of the 25 MPa water jets and from the reduced cutting speeds. While research overseas has concentrated on roadheading machines working in medium strength strata, the emphasis here is to optimize machine operating variables to deal with the hard South African coal and the frequently occurring sandstone roof and floor conditions.

STRATA CONTROL PROBLEM

The demand for increased coal production in recent years has led to mines being established in and planned for regions more remote from the existing coal producing areas. Since coal seams in these areas tend to be deeper than those previously mined, good strata control and the maximum extraction of reserves assume increasing importance. The programme of work is therefore largely directed to collecting information which will lead to a better understanding of the ground movements around total extraction panels and the strength of the coal pillars.

MINE DESIGN

Increased extraction of coal reserves in an economic and safe manner is of paramount importance to the coal mining industry. As a result, the Research Organization is concentrating on improving design procedures through monitoring ground movements and support systems in and around total extraction panels.

Longwall Mining

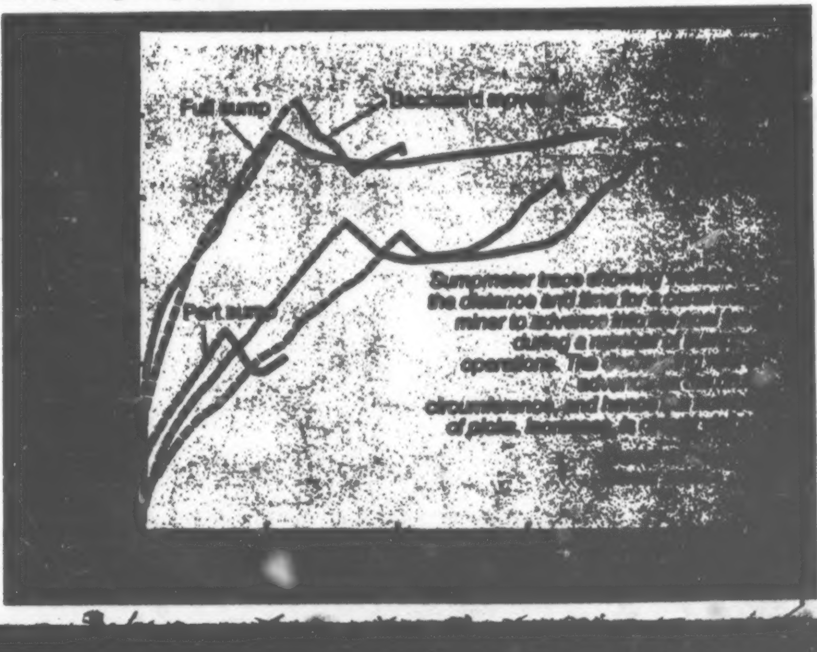
The support performance of 11 longwall installations operating in three coalfields, each with unique geological conditions, is being monitored in an on-going programme with the objective of improving the overall efficiency of longwall operations. To assist with this programme an intrinsically safe, single channel, low cost data logger has been developed.

Analysis of previously obtained data showed that only part of the problem of periodic loading of the supports, which is caused by the overhang of dolerite sills in the superincumbent strata, is solved by increasing the support resistance and upgrading the hydraulic supply. It was found that the supports only very infrequently reach their designed yield load and that the setting loads are well below the optimum.

The maintenance of the hydraulic supply system was identified as a critical area affecting the performance of existing longwall supports. Poor maintenance was found to lead to serious roof control problems and to eventually result in lower coal production.

Rib Pillar Mining

This method of total extraction shows great potential but time consuming delays incurred through the installation of wooden props for breakerline support can reduce machine availability by as much as 18 per cent. A further 18 per cent may be lost through general roof



Sumpmeter trace showing [illegible] the distance and time for a [illegible] miner to advance into the [illegible] during a number of [illegible] operations. The [illegible] circumference and hence [illegible] of picks, increases [illegible] support installation, reducing in total the potential production from a rib pillar panel by about one third.

The performance of a mechanized crawler mounted hydraulic breakerline support unit, which has been manufactured by a mining machine manufacturer, is being closely monitored.

A recent survey of roof falls in rib pillar extraction panels indicated that 90 per cent of falls can be directly attributed to geological conditions and poor mining practice. The results of this survey will assist in the formulation of guidelines for the design of rib pillar panels.

Protection of Surface Structures

Three panels which were extracted between three and five years ago have been re-surveyed to establish long-term subsidence of the ground surface. From the re-survey of the monitoring pegs over the solid abutments adjacent to total extraction panels, it was found that the subsidence displacement did not increase in vertical or horizontal directions over the years. In fact, only the seasonal changes of soil expansion and shrinkage have been detected. This finding can have considerable significance as far as the utilization of undermined land is concerned.

Most of the subsidence damage to surface structures from undermining by total extraction panels is caused by differential horizontal movements and not by the vertical displacement. A new 'radial survey' method was introduced to monitor the ground movements in these situations and to replace the previously used method of exclusive levelling of monitoring pegs. The new method determines all co-ordinates of a peg and from these the vertical and horizontal components of displacements can be obtained. Survey data are electronically recorded on tape in the field and fed directly into a desk top computer which evaluates all components of surface displacements.

Radial survey is being used by some collieries under the guidance of the Research Organization to monitor surface subsidence over those longwall panels which have a sub-critical span and partial failure of an overlying dolerite sill.

The effects of undermining on a tarred road by a longwall panel with dimensions 210 m wide and 120 m deep and with an extraction height of 2,8 m, were closely monitored. Frequent measurement of 200 survey pegs indicated clearly the mode and magnitude of the differential horizontal displacements which damaged the road. From these results it will be possible to determine the critical horizontal strains through comparing damaged and undamaged stretches of road, and to predict the degree of structural damage to a road under similar conditions.

A survey is being conducted to quantify the amount of coal which could potentially be lost as a result of rigid undermining regulations.

PILLAR DESIGN

The general trend towards deeper coal mine workings has increased the importance of pillar design, both as a means of support and in relation to percentage extraction. Research into these aspects is being conducted.

Design of coal pillars

The existing pillar design formula has been in use since 1967 and although it has performed very satisfactorily, it does not take into account certain important influences, namely: the regional differences in coal strength, the method of mining and the effect of high width to height ratios. Each of these influences is currently being investigated.

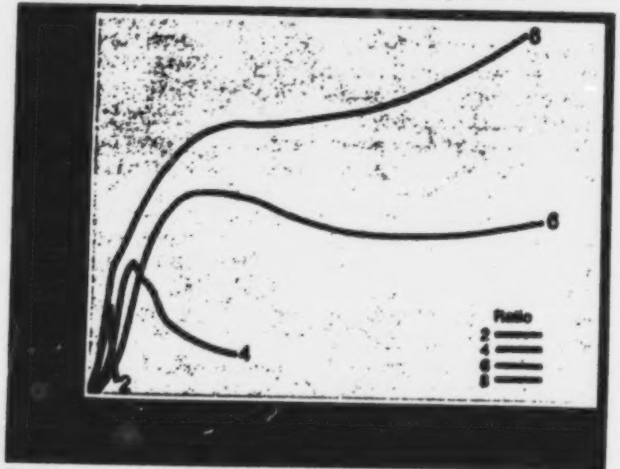
The present pillar design method neglects any variation in coal strength from place to place or seam to seam. Field surveys and practical experience suggest that there can be significant differences in the coal strength of the different localities. Individual seam strengths are being derived through a pillar rating or classification scheme. The scheme is based on a careful visual examination of underground conditions to assess the extent of deterioration.

Pillars formed by conventional drill and blast methods contain a perimeter zone of blast-induced fractures to a depth of about 0,3 m. This zone is absent in pillars formed by continuous miners and, since the present design formula was derived from case studies involving only drill and blast methods, it can be inferred that these pillars are overdesigned by 0,3 m.

It can also be shown, however, that the difference in strength of the two types of pillars is only significant at small pillar sizes of up to around 6 m by 6 m. At sizes greater than this the effect of the mining method on pillar strength diminishes rapidly.

An extended pillar formula was developed to determine the effects of large width to height ratios on pillar strength more satisfactorily. This formula is based on the formula presently used by the Industry but caters for those cases which were beyond the scope of the original pillar design formula which was valid only for pillars with relatively small width to height ratios. The extended pillar formula is of particular interest for deeper collieries which employ pillars with large width to height ratios.

Tensile crack in tarred road resulting from undermining by a longwall face. The road was closed to traffic and an extensive monitoring programme ascertained the response of the road to the strata movements. Some of the instrumentation employed is clearly visible in the photograph.



Stress-strain relationship of cylindrical sandstone specimens showing the effect on strength when the width to height ratio is increased from two to eight. The graph clearly shows the change in the mode of failure from brittle at low ratios, plastic at around four and five, to ductile behaviour at the larger ratios.

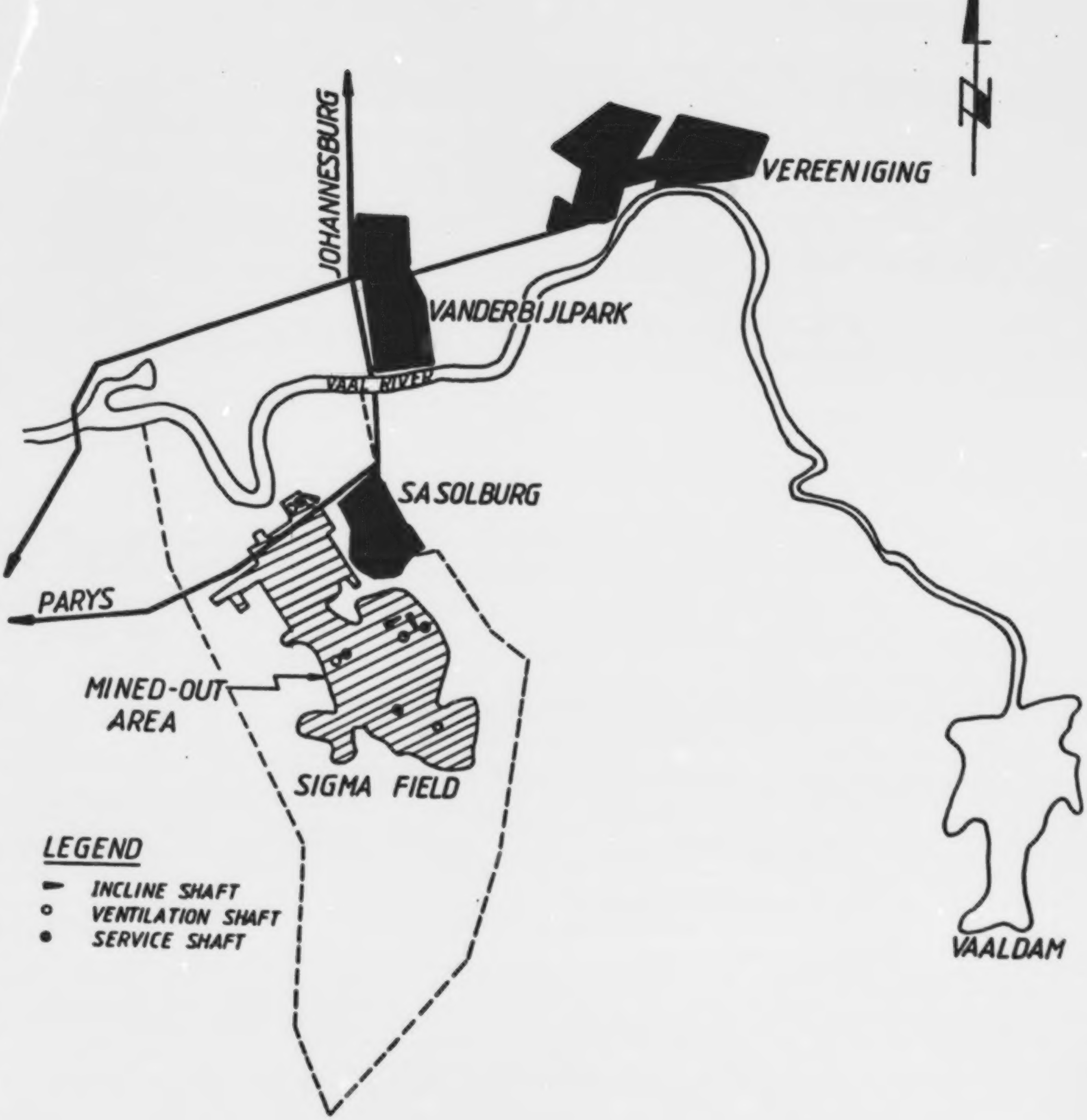

JOHANNESBURG
VEREENIGING
VANDERBIJLPARK
VAAL RIVER
SASOLBURG
PARYS
MINED-OUT AREA
SIGMA FIELD
VAALDAM
LEGEND
INCLINE SHAFT
VENTILATION SHAFT
SERVICE SHAFT

FIGURE 1 SIGMA COLLIERY LOCATION PLAN

	AVERAGE THICKNESS	CUMULATI DEPTH
OVERBURDEN	4.0m	4,0m
DOLERITE	40.0m	44.0m
SANDSTONE	6.0m	50.0m
DOLERITE	45,0m	95.0m
SANDSTONE & SHALE	40.0m	135.0m
COAL	0.5m	135.5m
MUDSTONE & SHALE	8.0m	143.5m
3 SEAM COAL	4.0m	147,5m
SANDSTONE	16.0m	163.5m
2B SEAM COAL	5.0m	168.5m
MUDSTONE	0.5m	169.0m
2A SEAM COAL	3,5m	172,5m
CONGLOMORITE	3,0m	175,5m
1 SEAM COAL	3,0m	178,5m
TILLITE	20,0m	198,5m

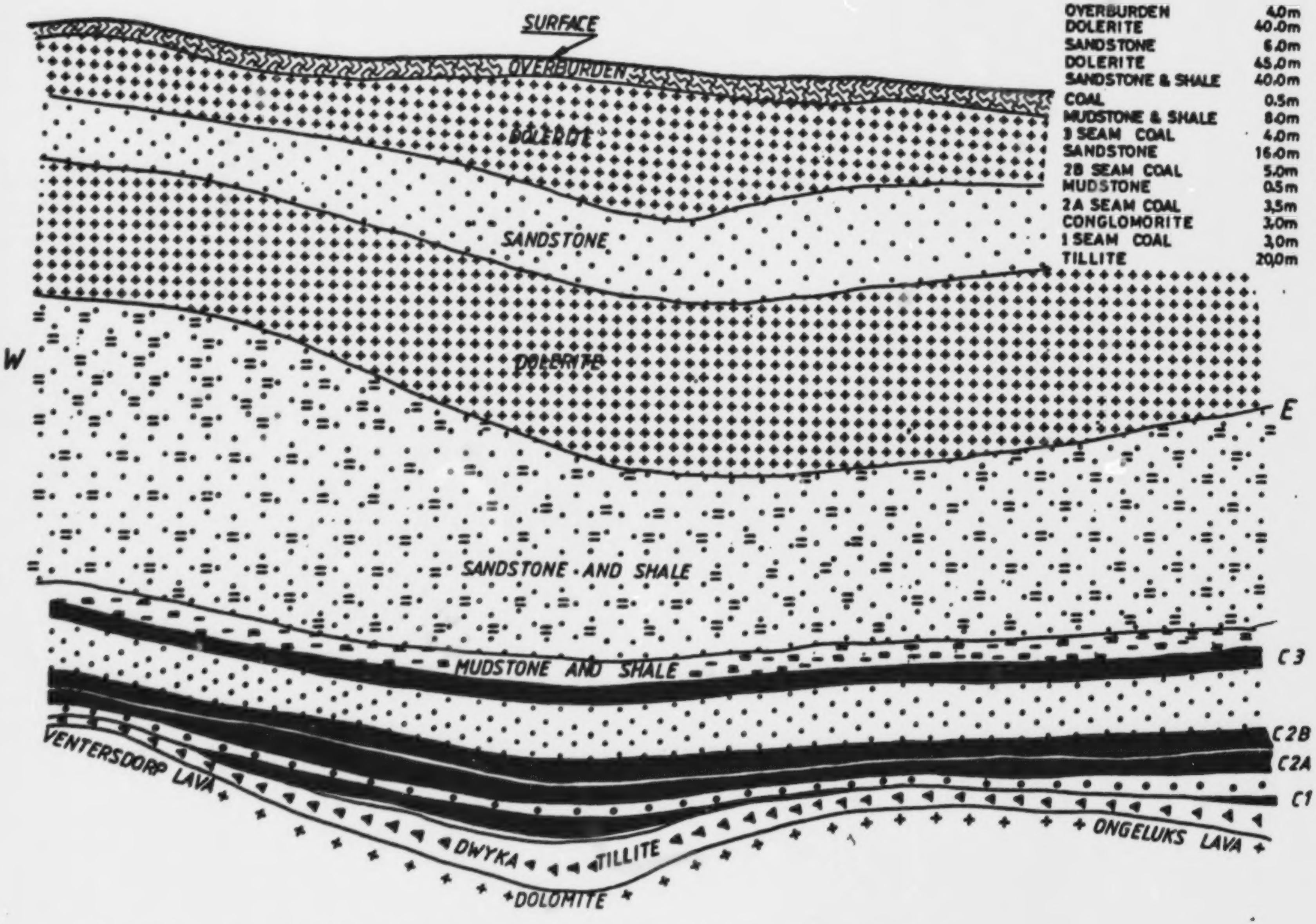

SURFACE
OVERBURDEN
DOLERITE
SANDSTONE
W
DOLERITE
E
SANDSTONE AND SHALE
MUDSTONE AND SHALE
C3
C2B
C2A
C1
VENTERSDORP LAVA
DWYKA
TILLITE
DOLOMITE
ONGELUKS LAVA

FIGURE 2 SIMPLIFIED STRATIGRAPHICAL PROFILE

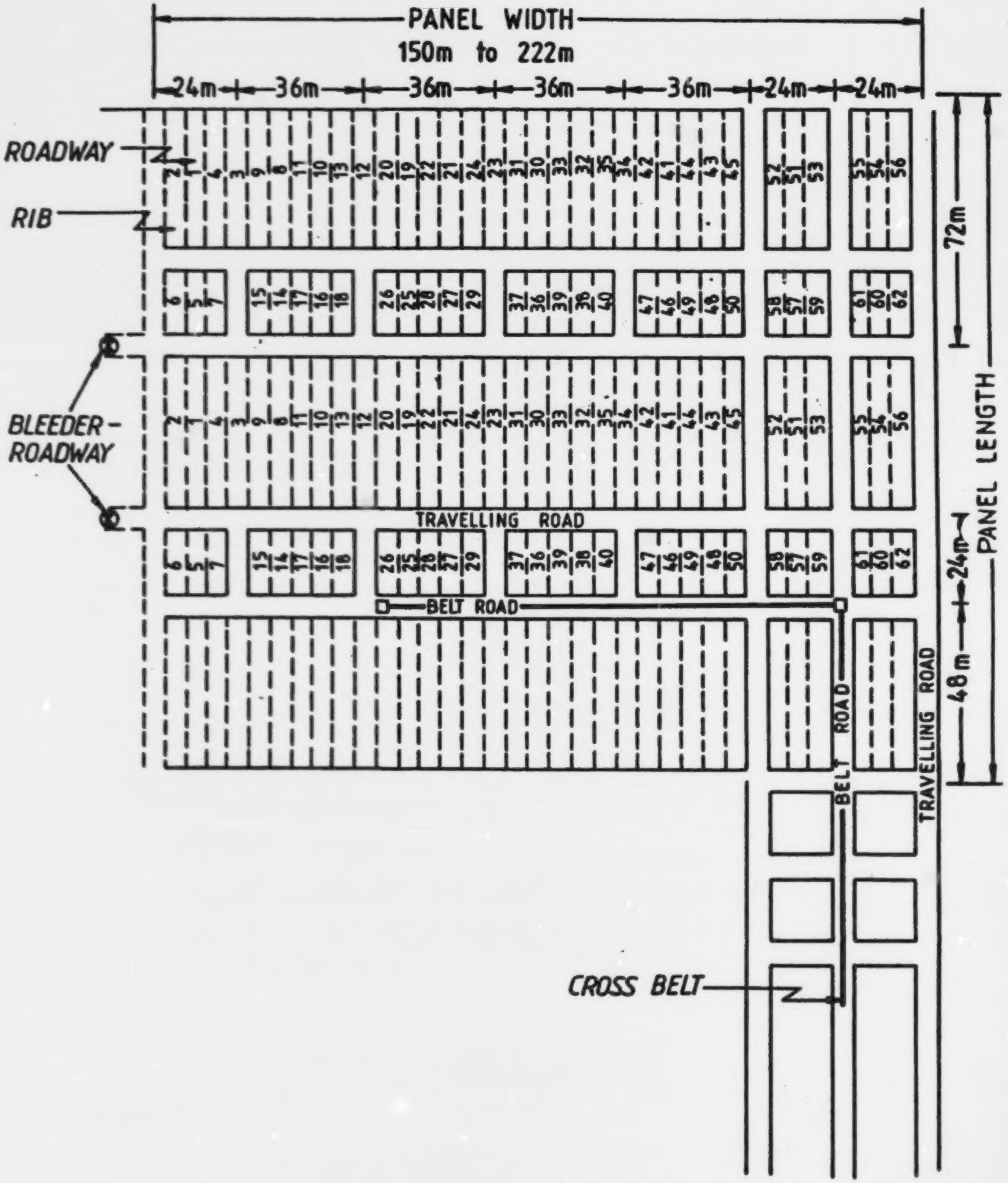

PANEL WIDTH
150m to 222m
24m
36m
36m
36m
36m
24m
24m
ROADWAY
RIB
BLEEDER-ROADWAY
TRAVELLING ROAD
BELT ROAD
72m
PANEL LENGTH
24m
48m
BELT ROAD
TRAVELLING ROAD
CROSS BELT

FIGURE 3 LAYOUT OF SIGMA RIB PILLAR EXTRACTION SHOWING CROSS BELT

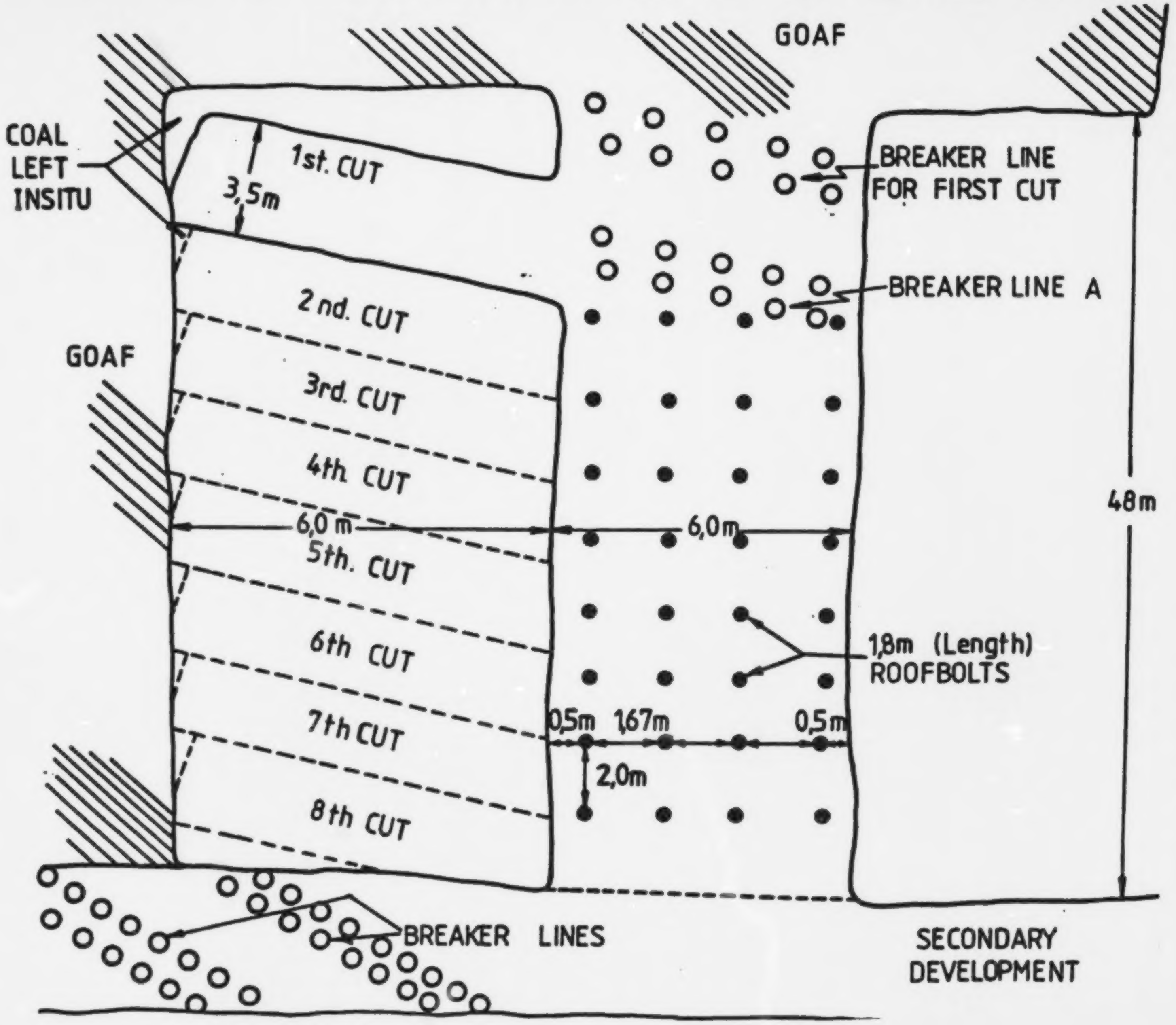

GOAF
COAL
LEFT
INSITU
1st. CUT
3,5m
BREAKER LINE
FOR FIRST CUT
BREAKER LINE A
GOAF
2 nd. CUT
3rd. CUT
4th. CUT
6,0 m
6,0m
48m
5th. CUT
6th CUT
1,8m (Length)
ROOFBOLTS
0,5m
1,67m
0,5m
7th CUT
2,0m
8th CUT
BREAKER LINES
SECONDARY
DEVELOPMENT

FIGURE 4 SEQUENCE OF CUTS FOR EXTRACTION OF PILLARS

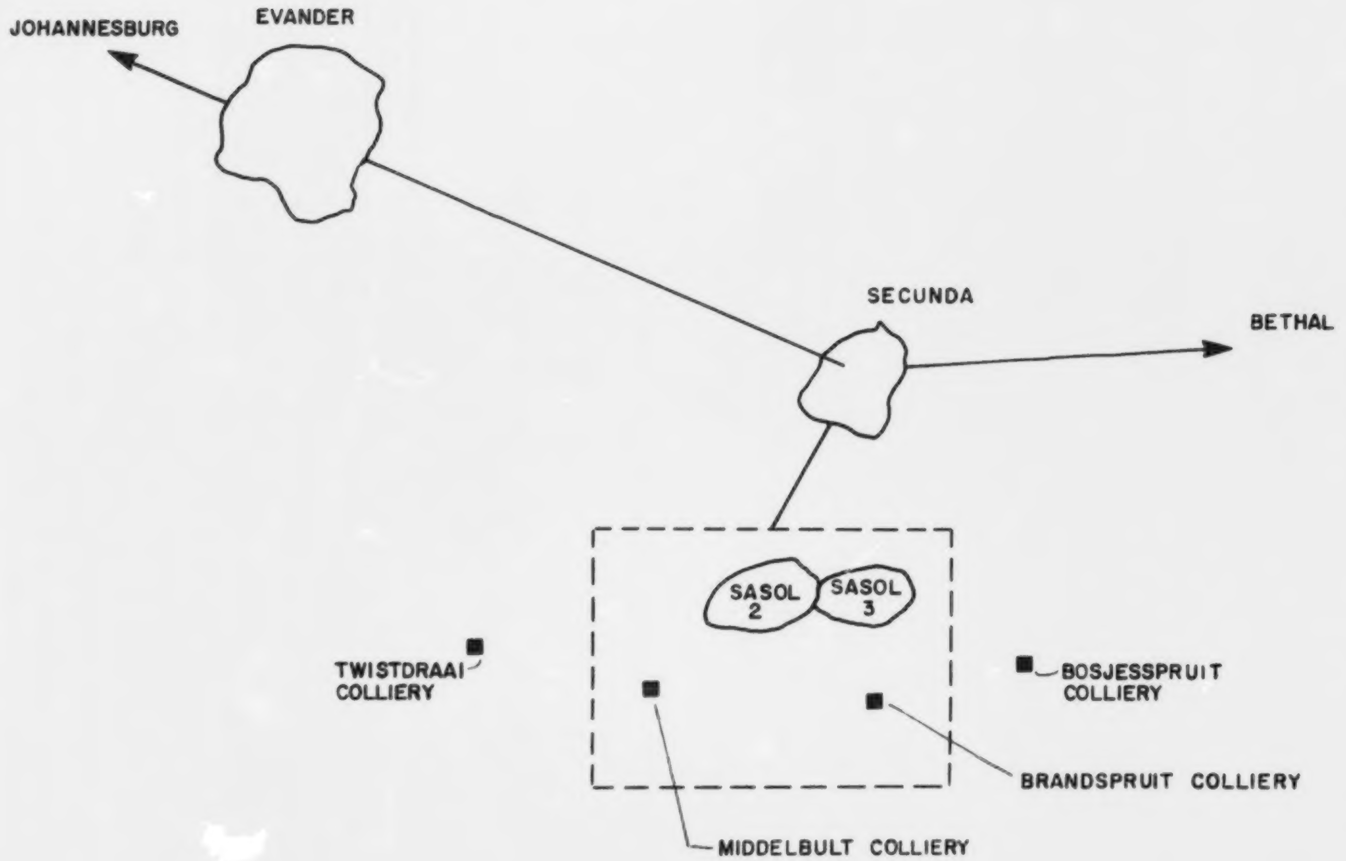

JOHANNESBURG
EVANDER
SECUNDA
BETHAL
SASOL 2
SASOL 3
TWISTDRAAI COLLIERY
BOSJESSPRUIT COLLIERY
BRANDSPRUIT COLLIERY
MIDDELBULT COLLIERY

FIGURE 5 LOCATION OF SECUNDA COLLIERIES & SASOL PLANTS

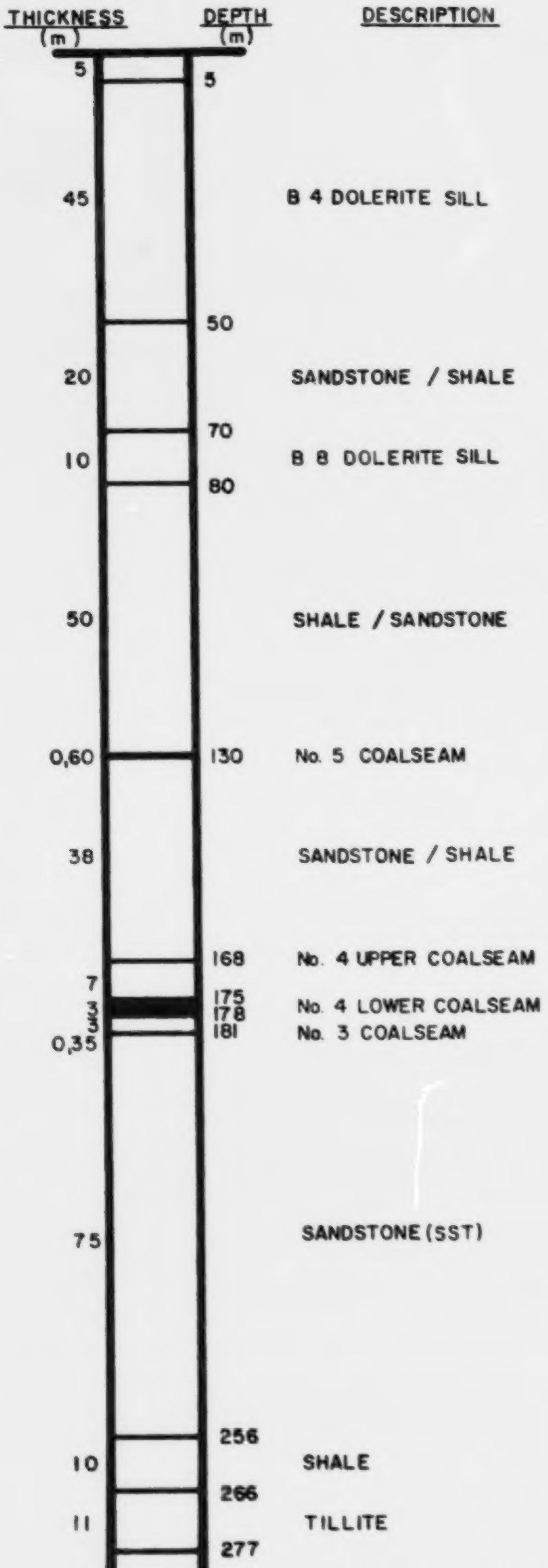

THICKNESS (m)
DEPTH (m)
DESCRIPTION
5
5
45
B 4 DOLERITE SILL
50
20
SANDSTONE / SHALE
70
10
B 8 DOLERITE SILL
80
50
SHALE / SANDSTONE
0,60
130
No. 5 COALSEAM
38
SANDSTONE / SHALE
168
No. 4 UPPER COALSEAM
7
175
3
178
No. 4 LOWER COALSEAM
3
181
No. 3 COALSEAM
0,35
75
SANDSTONE (SST)
256
10
SHALE
266
11
TILLITE
277

FIGURE 6 SECUNDA COALFIELD TYPICAL GEOLOGICAL SECTION BRANDSPRUIT COLLIERY

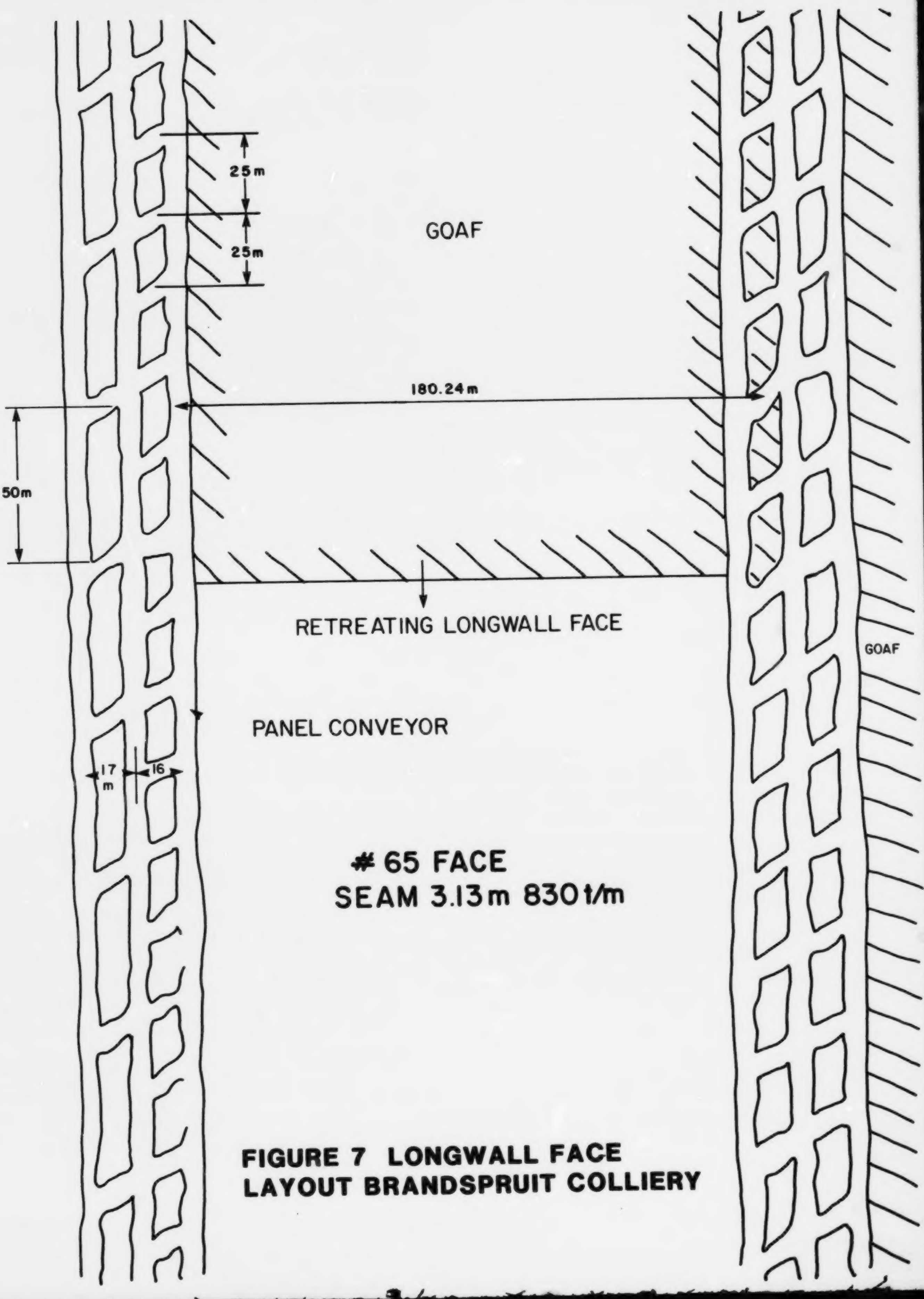

GOAF
25m
25m
180.24m
50m
RETREATING LONGWALL FACE
GOAF
PANEL CONVEYOR
17 m
16
#65 FACE
SEAM 3.13m 830t/m

FIGURE 7 LONGWALL FACE LAYOUT BRANDSPRUIT COLLIERY

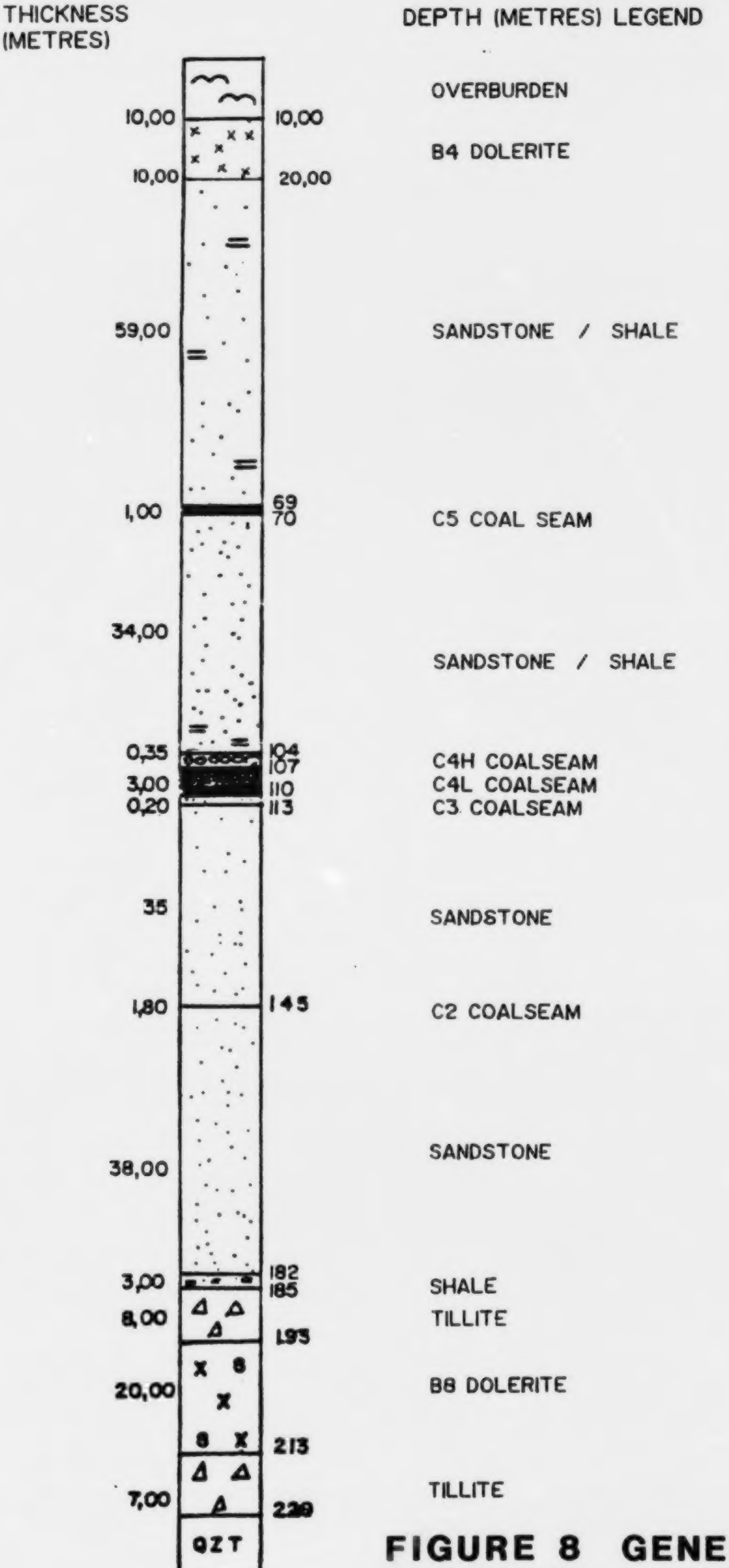
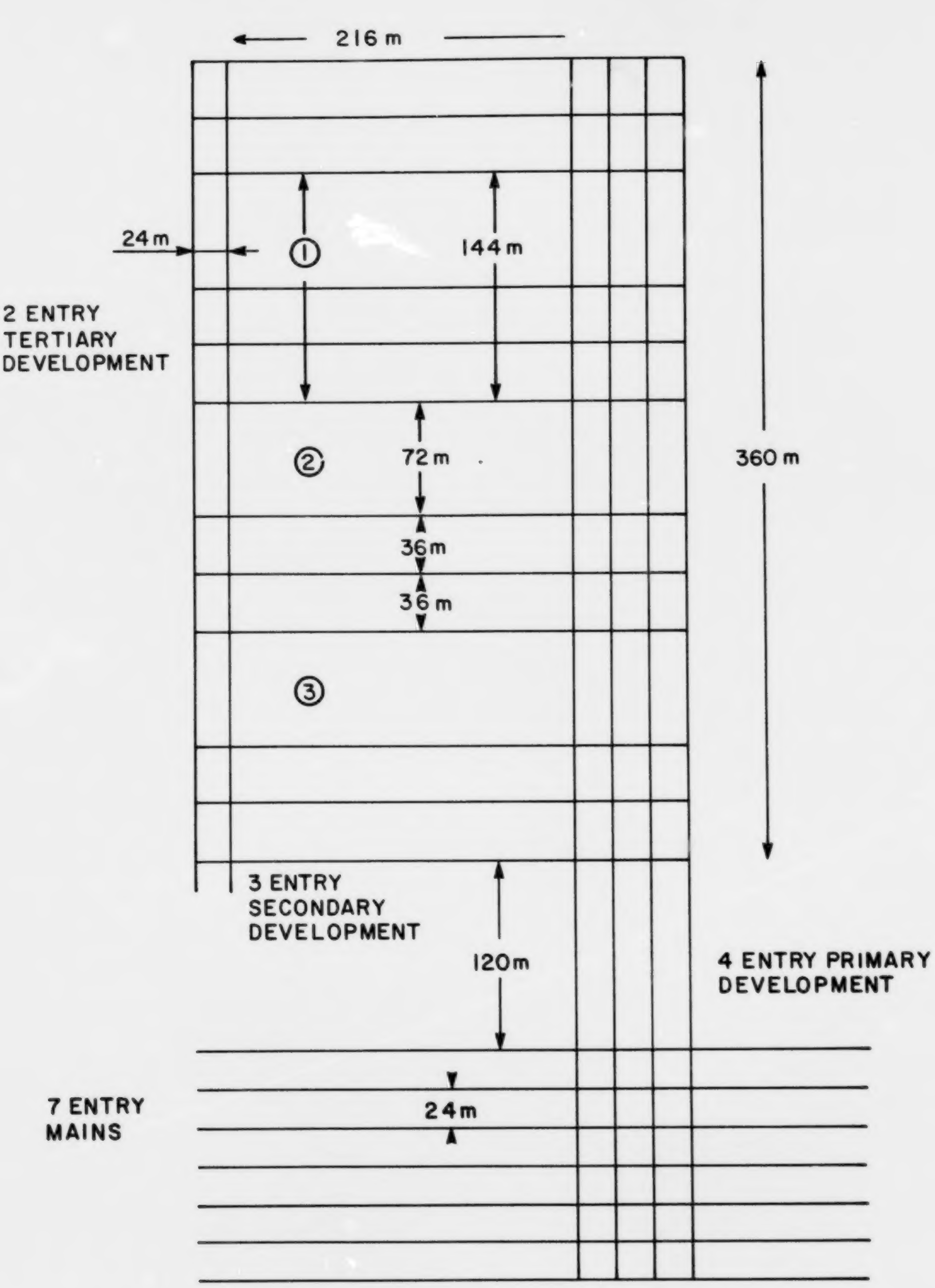

THICKNESS (METRES)
DEPTH (METRES) LEGEND
OVERBURDEN
10,00
10,00
B4 DOLERITE
10,00
20,00
59,00
SANDSTONE / SHALE
1,00
69
70
C5 COAL SEAM
34,00
SANDSTONE / SHALE
0,35
104
107
C4H COALSEAM
3,00
110
C4L COALSEAM
0,20
113
C3 COALSEAM
35
SANDSTONE
1,80
145
C2 COALSEAM
38,00
SANDSTONE
3,00
182
185
SHALE
8,00
TILLITE
193
20,00
B8 DOLERITE
213
7,00
229
TILLITE
QZT

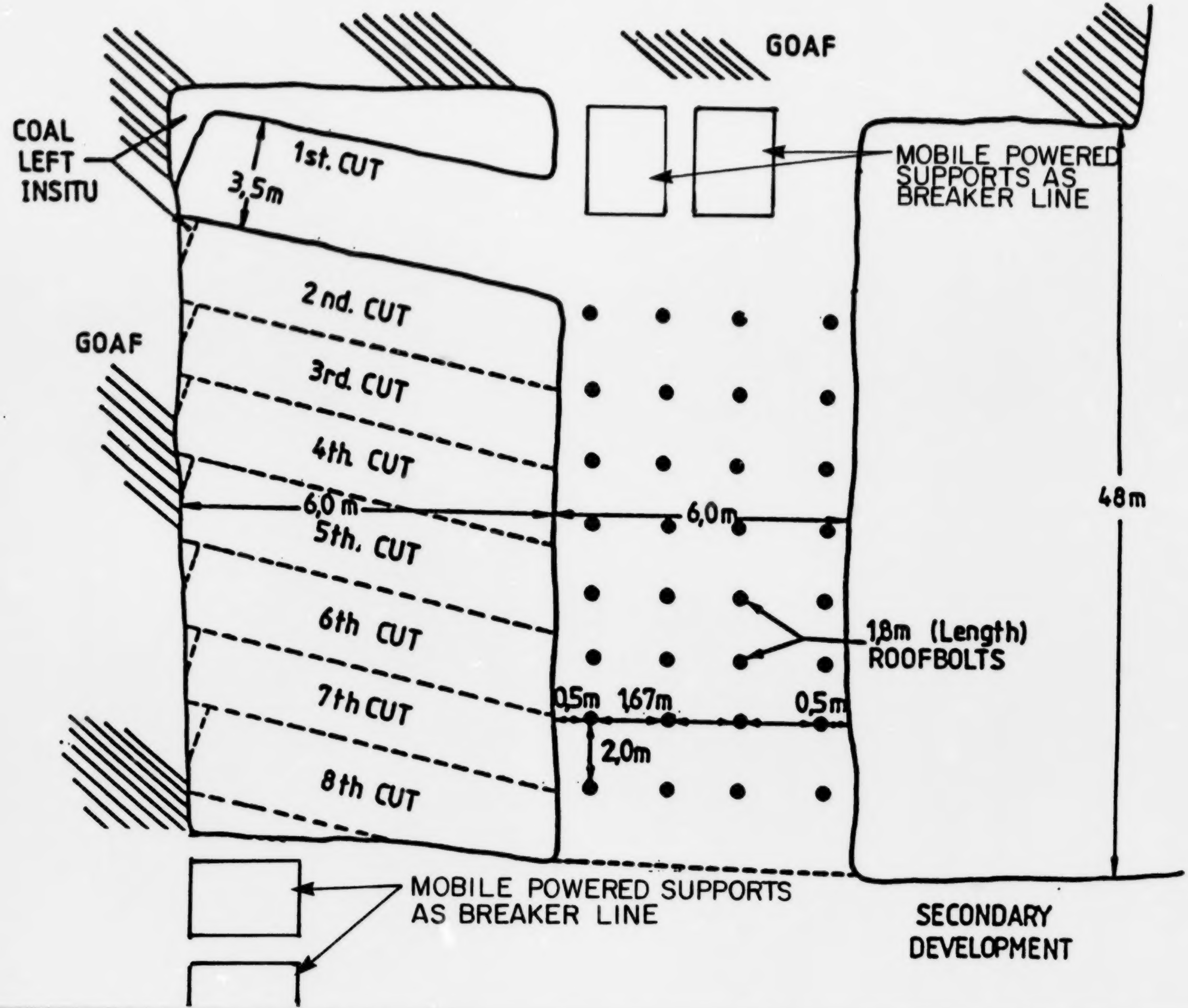
FIGURE 8 GENERAL PROFILE MIDDELBULT COLLIERY


216 m
24 m
①
144 m
2 ENTRY
TERTIARY
DEVELOPMENT
②
72 m
36 m
36 m
③
360 m
3 ENTRY
SECONDARY
DEVELOPMENT
120 m
4 ENTRY PRIMARY
DEVELOPMENT
7 ENTRY
MAINS
24 m

CYCLE — DEVELOP BLOCK ① — 3 WEEKS
— DEPILLAR BLOCK ① — 3 WEEKS

FIGURE 9 RIB PILLAR PANEL LAYOUT
MIDDELBULT COLLIERY

FIGURE 10 USE OF CRAWLER MOUNTED POWERED SUPPORTS AS A BREAKER LINE


GOAF
COAL LEFT INSITU
1st. CUT
3,5m
MOBILE POWERED SUPPORTS AS BREAKER LINE
2nd. CUT
GOAF
3rd. CUT
4th. CUT
6,0 m
6,0m
48m
5th. CUT
6th CUT
1,8m (Length) ROOFBOLTS
7th CUT
0,5m
1,67m
0,5m
2,0m
8th CUT
MOBILE POWERED SUPPORTS AS BREAKER LINE
SECONDARY DEVELOPMENT

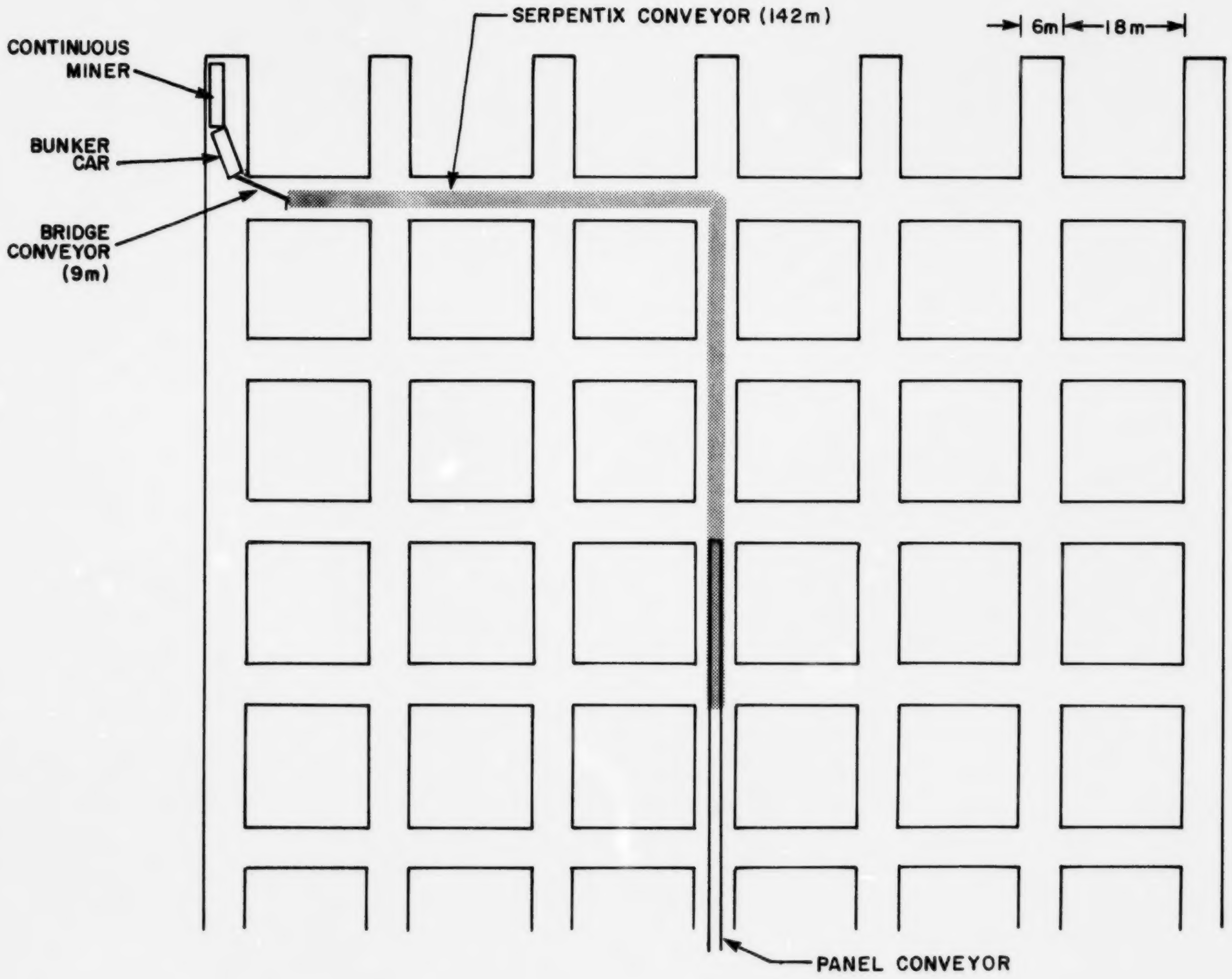

CONTINUOUS MINER
BUNKER CAR
BRIDGE CONVEYOR (9m)
SERPENTIX CONVEYOR (142m)
6m
18m
PANEL CONVEYOR

FIGURE 11 MIDDELBULT COLLIERY 7-ENTRY MAIN DEVELOPMENT WITH CONTINUOUS HAULAGE SYSTEM

APPENDIX B

A. LIST OF PLACES OF LEARNING CONTACTED

B. LIST OF RESEARCH ESTABLISHMENTS AND MINES CONTACTED

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Attention: Mr. G.E. Boast
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APPENDIX C

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APPENDIX D

RELEVANT TECHNICAL PAPERS

REFERENCE PAPERS

1. "Rib Pillar Extraction: Achieving High Production Rates at SASOL operation's Sigma Colliery, R.S.A."

   Phil. C. Crous - Mine Manager, Sigma Colliery

2. "Old Principle: New Concept"

   Derek Harvey - Atlas Copco Canada Inc.

3. "Geotechnical Evaluation of Wongawilli Extraction System at Coal Cliff Colliery, Australia"

   G. Skybey - ACIRL

4. "Automation in Coal Mining"

   M.W. Thring - Queen Mary College, London

5. "Mining Without Men Going Underground"

   M.W. Thring - Queen Mary College, London

6. "Robotics in Mining - A Canadian View"

   J. Pathak - CANMET

RIB PILLAR EXTRACTION : ACHIEVING HIGH PRODUCTION RATES AT SASOL OPERATIONS'S, SIGMA COLLIERY, REPUBLIC OF SOUTH AFRICA

BY

PHIL C CROUS - MINE MANAGER

SIGMA COLLIERY

SYNOPSIS

The importance of total extraction systems in South Africa is self-evident as the increase in the extractable coal reserves will create additional coal business opportunities and allow present ventures to live longer.

Rib-Pillar Extraction is a high extraction coal mining method which has successfully been incorporated into the Sigma mining system and was largely made possible by the enlightened efforts of a dynamic and capable team.

The method could have limitations in circumstances where coal depth is in excess of 400 m and should be carefully examined where the overburden is composed of very competent rock like massive sandstones.

Rib-Pillar Extraction allows for easy conversion from conventional Bord and Pillar mining especially where continuous miners are already introduced.

It is a low capital, low cost, flexible and concentrated method of mining.

1 SIGMA COLLIERY

The Sigma coalfield lies west and south-west of the town Sasolburg which is approximately 80 km south of Johannesburg (Figure 1).

Mining operations at Sigma are concentrated in three main areas which are interconnected, each of which has its own network of services, incline and ventilation shafts and surface storage facilities.

The plus 6,0 million tons per annum output of the mine is consumed in total by the Sasol One Synthetic Fuel Plant, and is supplied as follows :

6 Mechanised Bord-and-Pillar sections	30%
2 Double continuous miner rib-pillar extraction units	32%
1 Pillar extraction continuous miner	9%
1 Longwall face with continuous mining development	29%
	100%

The Sigma Coal basin comprises three main coal seams dipping from north to south at approximately four degrees.

The three coal seams vary in thickness but on average are as follows which refers to mineable coal.(See figure 2)

No 3 seam (top C3)	2,64m
No 2B seam (middle C2B)	3,04m
No 2A seam (bottom C2A)	2,91m

The coal field is largely overlain by a competent dolerite sill varying in thickness from 40 m in the northern area to 100 m in the southern area as shown in figure 2.

2 1973 OIL CRISES

In the wake of the 1973 oil crisis, coal assumed a new and important economic role world-wide, but nowhere more important than in South Africa where the bulk of the energy requirements have and will continue to be drawn from coal.

It is of supreme importance that South African mining men experiment with, investigate and innovate mining methods to ensure maximum utilisation of available coal reserves. It is in fact, this ideal, which has motivated Sigma to set the pace in high extraction underground mining methods in South Africa.

3 OBJECTIVES OF RIB-PILLAR EXTRACTION

To outline these objectives it is worth while considering the following advantages as these features were initially objectives when other similar systems were designed in the USA and Australia.

3.1 ADVANTAGES OF RIB-PILLAR EXTRACTION

a Obtain high percentage "in panel" extraction in excess of 95%.

b Concentrated mining - creates a single working place for increased supervision.

c Extract coal in a stress relieved area.

d Less intersections than conventional pillar extraction, thereby reducing roof support problems.

e Continuous miner operators always under supported roof.

f Relative low capital cost.

g Relative low working cost.

h Rib-pillar extraction is a very flexible mining method - isolated and small reserve areas can be mined effectively

3.2 POSSIBLE DISADVANTAGES OF RIB-PILLAR EXTRACTION

a The extraction of a particular rib must be completed prior to week-end to avoid crushing - In South Africa the Mines and Works Act prohibits Sunday work.

b Possibility of roof falls on the continuous miner especially when cutting the rib near an intersection - the rate of extraction should therefor be high in these problem areas.

c Ventilation and spontaneous combustion problems due to ventilation over the goaf (gob)

4 RIB-PILLAR EXTRACTION - A COMPLETE MINING SYSTEM

Rib-pillar extraction is a method especially designed for the continuous miner in the stooping process. With this method extraction takes place in a solid block of coal whereby the failure risk is reduced. This method also proved viable under severely faulted and disturbed roof conditions although the production output diminishes.

To date, 2 260 000 metric ton has been mined at Sigma Colliery by Rib-pillar extraction. Experimentation with different layouts proved that adding a high capacity cross belt to reduce on shuttle car travelling distance, improves production output to a record breaking 4 150 metric ton in an eight hour shift with a single continuous miner.

At present the production target at Sigma for a single continuous miner operation is 1 490 metric tons per shift. For a double continuous miner operation the planned performance is 2 040 metric tons per shift.

A reasonable objective for a double continuous miner section under the supervision of one miner comes to 130 000 metric tons per month, although a performance of 158 994 tons was reached in the calendar month of June 1982.

5 RIB-PILLAR EXTRACTION PANEL LAYOUT

Primary development consisting of three roadways i.e. a belt road, travelling road and companion are driven. Secondary development consisting of a travelling road and a belt road are then developed perpendicularly to the primary development roads. (See figure 3). The secondary development is repeated at 72 m centres along the panel length, while the length of a rib is 48 m. (See figure 3).

Panel lengths are normally in the order of 1 000 m and panel width approximately 200 m, depending on the features of the dolerite sill above. Due to the ventilation system over the goaf (gob) the panel width was recently reduced to 180 m.

Resin roofbolts with point-anchor, i.e. one capsule of resin with each bolt, is used in both primary and secondary development roadways. Refer to figure 3 for layout plan and sequence of extraction.

6 MINING CYCLE AND SUPPORT

The sequence of extraction is explained by the numbers in figure 3. When the ribs are extracted it is very similar to cutting a loaf of bread as per figure 4.

The first roadway is cut 6 m wide, piercing the solid block of coal for 48 m up to the previous goad. A rib of 6 m wide is thus formed (numbered 2 in figure 3), which will now be sliced away almost the same way as a loaf of bread. Refer to the numbered cuts in figure 4.

A timber breaker line is installed prior to the first cut and on completion of the first cut a new breaker line is installed, shown as breaker line A in figure 4. The first breaker line is then withdrawn, using wire rope and a loaded shuttle car. The second cut may then be taken and the cycle repeated untill the rib is extracted. Goafing normally takes place as breaker lines are removed. No roofbolts are required during rib removal as the continuous miner operator never works under unsupported roof.

The Mines and Works Regulation in South Africa allows us to cut 12 m ahead of the last row of bolts and thus the continuous miner has to move out when that distance is reached so that the roofbolter can move in to commence bolting. Therefore in figure 3 roadway 1 is cut for 12 m and the miner moves to roadway 3 to cut another 12 m. When that is completed roadway 1 has been roofbolted and the sequence starts again. There is room for improvement here - mounting roofbolters on the continuous miner will increase its productivity.

The 6 m rib width is determined by the length of the continuous miner specifically from the furthest reach of the cutting drum to the operator position.

7 ROCK MECHANICS

To allow the extraction of coal in a stress-relieved area the maximum stress from the goaf line must be considered and no roadways should be driven in this particular area parallel to the goaf line.

In the case of Sigma, this maximum stress is expected 17 m from the goaf line.

No problems have been experienced in the current extraction of 3,0 to 3,5 m high coal seams.

8 RIB-PILLAR EXTRACTION IN THICK COAL SEAMS

Thick seams of ± 9,0 m could possibly be extracted by taking a double lift in the same coal seam. At Sigma where the 2A and 2B (figure 2) seams have a parting of 1,0 to 2,0 m this double lift operation looks promising. Experiments at Collinsville Coal Company near Townsville, Australia, showed this could be done in a process of mining the top portion first whilst wooden dowelling 2 m down into the floor of main and secondary roadways is done as shown in figure 6. Pillars are superimposed as the second lift or bottom lift is taken 2,0 m below the top lift. The 2,0 m thus left in the roof can be extracted when the continuous miner is moving backwards to the secondary roadway. Such a trial will commence during April 1985 on Sigma Colliery.

9 VENTILATION

Ventilation is normally via the goaf (gob) to a pre-developed bleeder roadway. Piercing into this bleeder roadway takes place with retreat. One of the three primary development roadways can also be used as a return roadway and a bifurcated* fan returns air from the development end into the return airway. This provides an alternative return airway in the event of the goaf choking-up. refer to figure 5 for ventilation and section layout.

The reason for ventilating over the goaf is to contain gas in the goaf and to prevent it from coming into the section. In South Africa areas of the mine are sealed off in order to contain spontaneous combustion.

10 PERCENTAGE EXTRACTION

Rib-pillar extraction yields a percentage "in panel" extraction rate of approximately 95% at Sigma. This is more than twice that for mechanised Bord-and-Pillar at the same depth and even yields an advantage over Longwall mining. This is due to the fact that the only height limitation in extracting the rib is the maximum cutting height of the continuous miner. In the case of longwall at Sigma a constant layer of at least 0,6 m coal has to be left in the roof to protect the overlying shale against weathering. In Rib-pillar extraction barrier pillars are removed whereas at present, in the case of longwall mining they are left in situ thereby reducing "in panel" extraction to 85%.

* A "Bifurcated" fan is one where the motor is housed in a seperate compartment so that the exhaust air passes around the motor without coming in contact with it.

11 HIGH PRODUCTION RATES

The installation of a high capacity cross belt with a feeder breaker allows the reduction of shuttle car travelling distance whereby high productivity is obtained. The double continuous miner section requires two cross belts to be installed which proved higher manpower productivity due to concentrated mining. The average tons per shift over a period of 24 months for the double continuous miner operation comes to 1 300 tons per shift or 22 000 tons per week (17 production shifts) depending on the geological conditions.

The major advantage of the cross belt is that the panel width could be adjusted anywhere between 100 and 200 m, allowing flexibility when required. Flexibility is required to cope with the critical span of the dolerite sill overlying the coal bearing strata.

All belt extentions/reductions are done on the maintenance shift of which there is one per week. The cross belt needs shortening about once a week as rib extraction proceeds along the block of coal.

12 COST COMPARISON AND LABOUR COMPLEMENT PER SHIFT FOR RIB-PILLAR EXTRACTION WITH TWO CONTINUOUS MINERS

12.1 COST COMPARISON OF VARIOUS MINING METHODS

	MECHANISED BORD AND PILLAR	LONGWALLING	RIB-PILLAR EXTRACTION
Cost	100%	97,7%	84,3%
In panel productivity			
Tons/manshift	20,9	39,34	21,88

12.2 OPERATING LABOUR (on 3 shifts per day, 6 days per week)

Mine Overseer	1/3
Shiftboss	2/3
Miners	1
Relief/General Miner	1/3
Operators and General	31 1/3
TOTAL	33 2/3

12.3 MAINTENANCE LABOUR

Foreman	1/3
Electromechanics	1 1/3
Operators	6 2/3
	8 1/3

The total manpower complement on a three shift basis thus comes to 42 people.

12.4 PRODUCTIVITY PER MANSHIFT

The productivity per manshift for Sigma Colliery on the whole is approximately 10 tons per manshift and the mine received the National Institute for Productivity award in 1982.

The in panel productivity per manshift for Rib-pillar extraction is 21,88 tons per manshift.

13 FUTURE IMPROVEMENTS

It is of the utmost importance to increase our productivity in South Africa and there is some possibilities in Rib-pillar extraction that needs further investigation :

13.1 Roofbolters on the continuous miner would cut travelling time down and could lead to a productivity increase of about 10%.

13.2 Installing a continuous haulage behind the continuous miner would cut down the labour complement and utilize the continuous miner to its full capacity.

13.3 Replacing the timber breaker lines with hydraulic support is well underway. Difficulty was experienced with the walking shield type of support originally designed as it could not negotiate the difference in floor elevation. Underway now is a design on caterpillar tracks that can be easily transported.

CONCLUSION

Rib-pillar extraction has proved itself a viable high extraction mining method and has definite application in coal seams that are not specifically suited to other high extraction methods and it is capable of high production rates especially when the proposed changes have taken place.

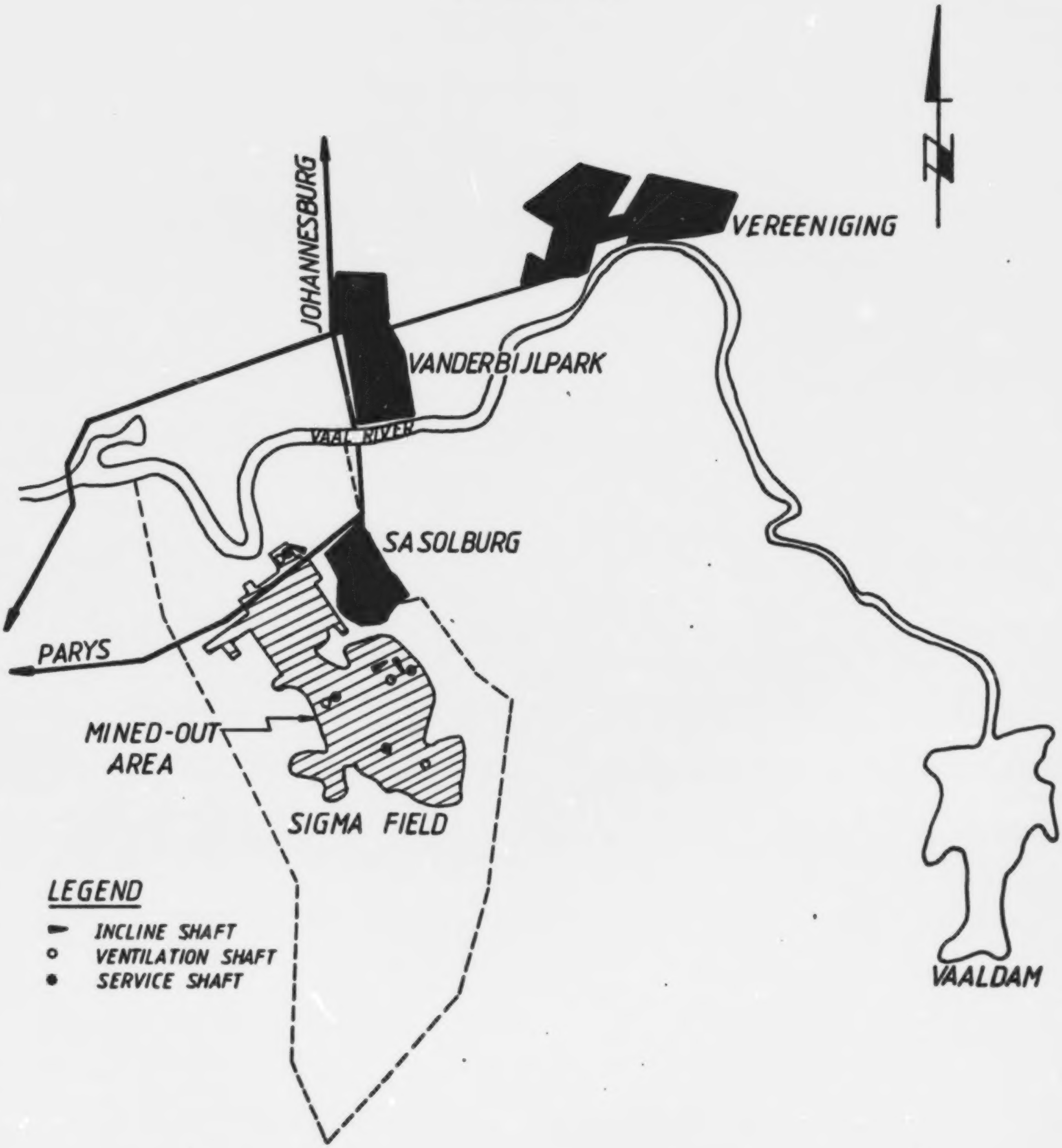
It is a flexible mining method which has proved to be safe and economically favourable when compared with other mining methods under similar conditions i.e. seam height of 3,5 m and depth below surface not exceeding 400 m.

PCC/ZK

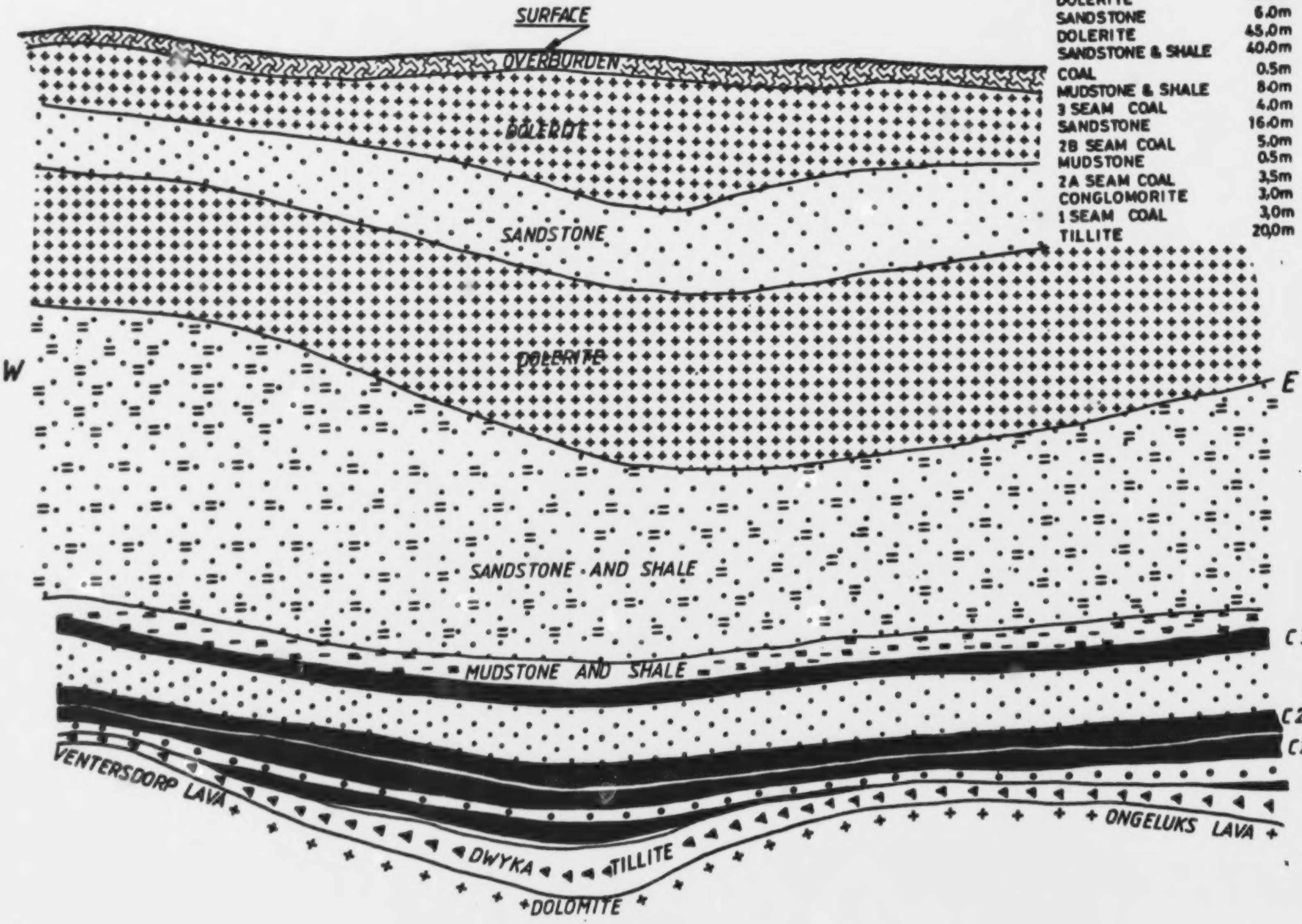
19.12.1984

FIGURE 1

SIGMA COLLIERY
LOCALITY PLAN


N
JOHANNESBURG
VEREENIGING
VANDERBIJLPARK
VAAL RIVER
SASOLBURG
PARYS
MINED-OUT AREA
SIGMA FIELD
VAALDAM
LEGEND
INCLINE SHAFT
VENTILATION SHAFT
SERVICE SHAFT

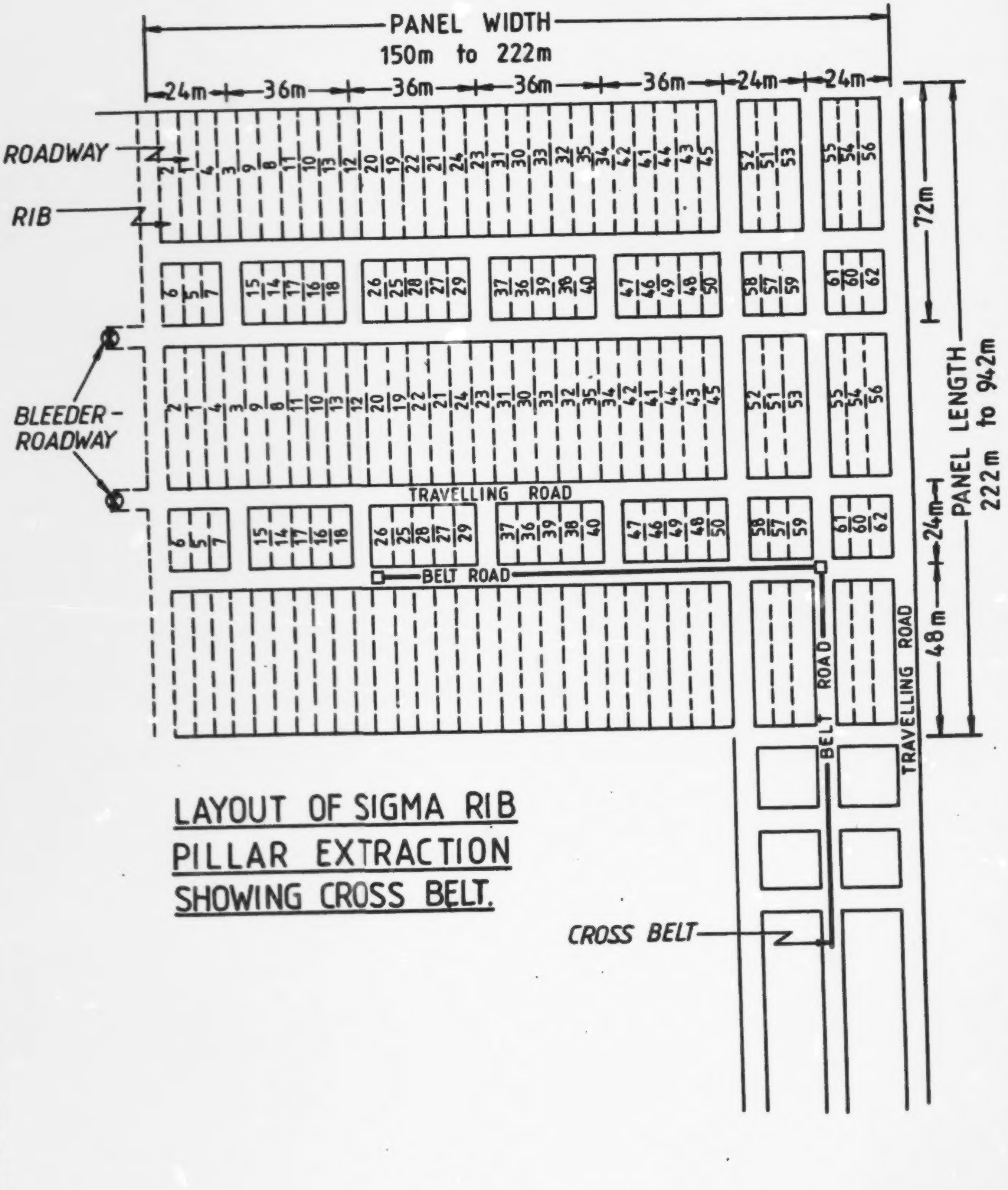
SIMPLIFIED STRATIGRAPHICAL PROFILE (CENTRAL PORTION)


SURFACE
OVERBURDEN
DOLERITE
SANDSTONE
DOLERITE
W
E
SANDSTONE AND SHALE
MUDSTONE AND SHALE
C 3
C2B
C2A
C1
VENTERSDORP LAVA
DWYKA
TILLITE
DOLOMITE
ONGELUKS LAVA

	AVERAGE THICKNESS	CUMULATIVE DEPTH
OVERBURDEN	4,0m	4,0m
DOLERITE	40.0m	44.0m
SANDSTONE	6.0m	50.0m
DOLERITE	45,0m	95.0m
SANDSTONE & SHALE	40.0m	135.0m
COAL	0.5m	135.5m
MUDSTONE & SHALE	8.0m	143.5m
3 SEAM COAL	4.0m	147,5m
SANDSTONE	16.0m	163.5m
2B SEAM COAL	5.0m	168.5m
MUDSTONE	0.5m	169.0m
2A SEAM COAL	3,5m	172,5m
CONGLOMORITE	3,0m	175,5m
1 SEAM COAL	3,0m	178,5m
TILLITE	20,0m	198,5m

FIGURE 2

FIGURE 3


PANEL WIDTH
150m to 222m
24m
36m
36m
36m
36m
24m
24m
ROADWAY
RIB
BLEEDER-ROADWAY
TRAVELLING ROAD
BELT ROAD
BELT ROAD
TRAVELLING ROAD
72m
24m
48m
PANEL LENGTH
222m to 942m
CROSS BELT

LAYOUT OF SIGMA RIB PILLAR EXTRACTION SHOWING CROSS BELT.

FIGURE 4

SEQUENCE OF CUTS FOR EXTRACTION OF PILLARS

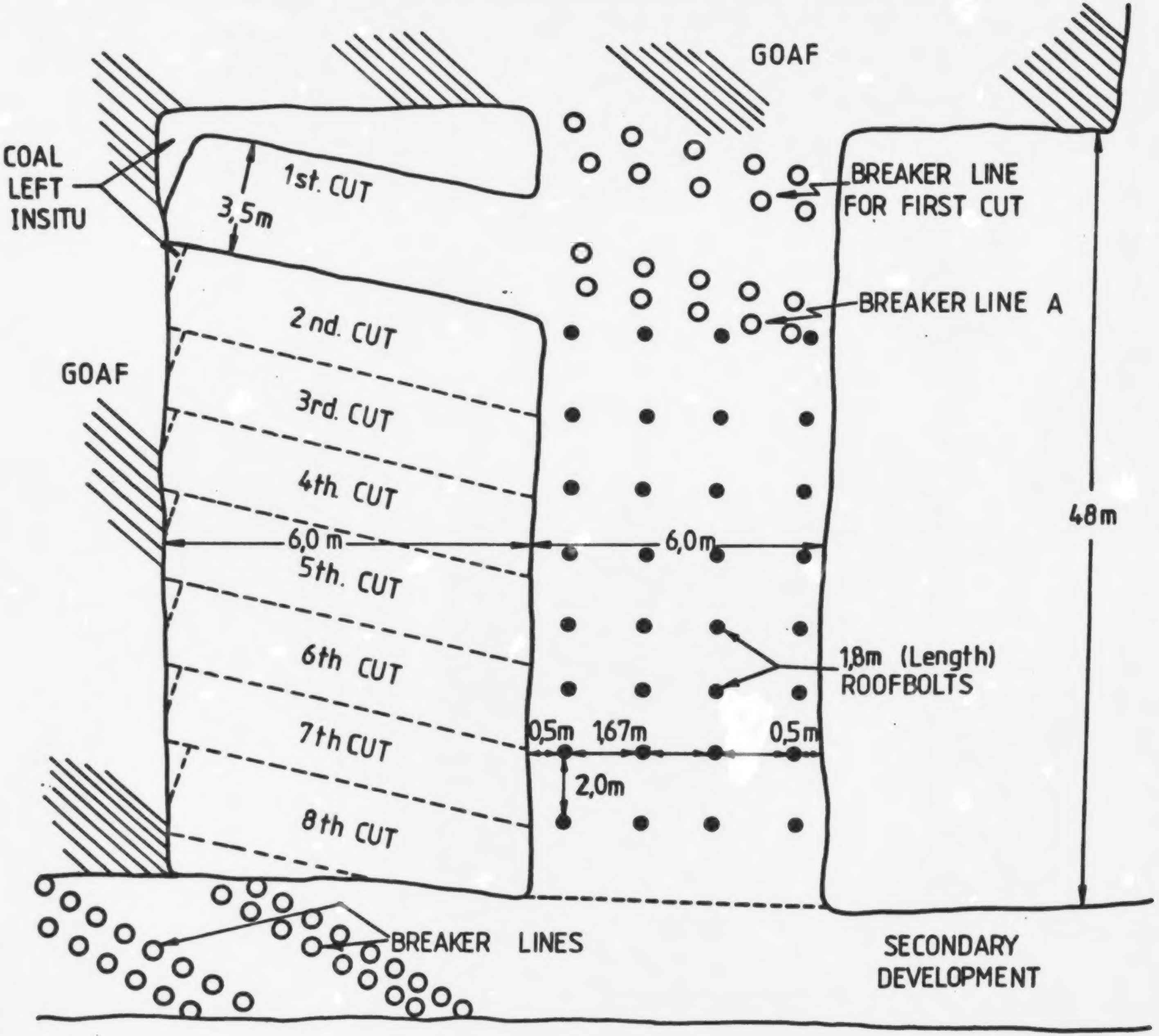
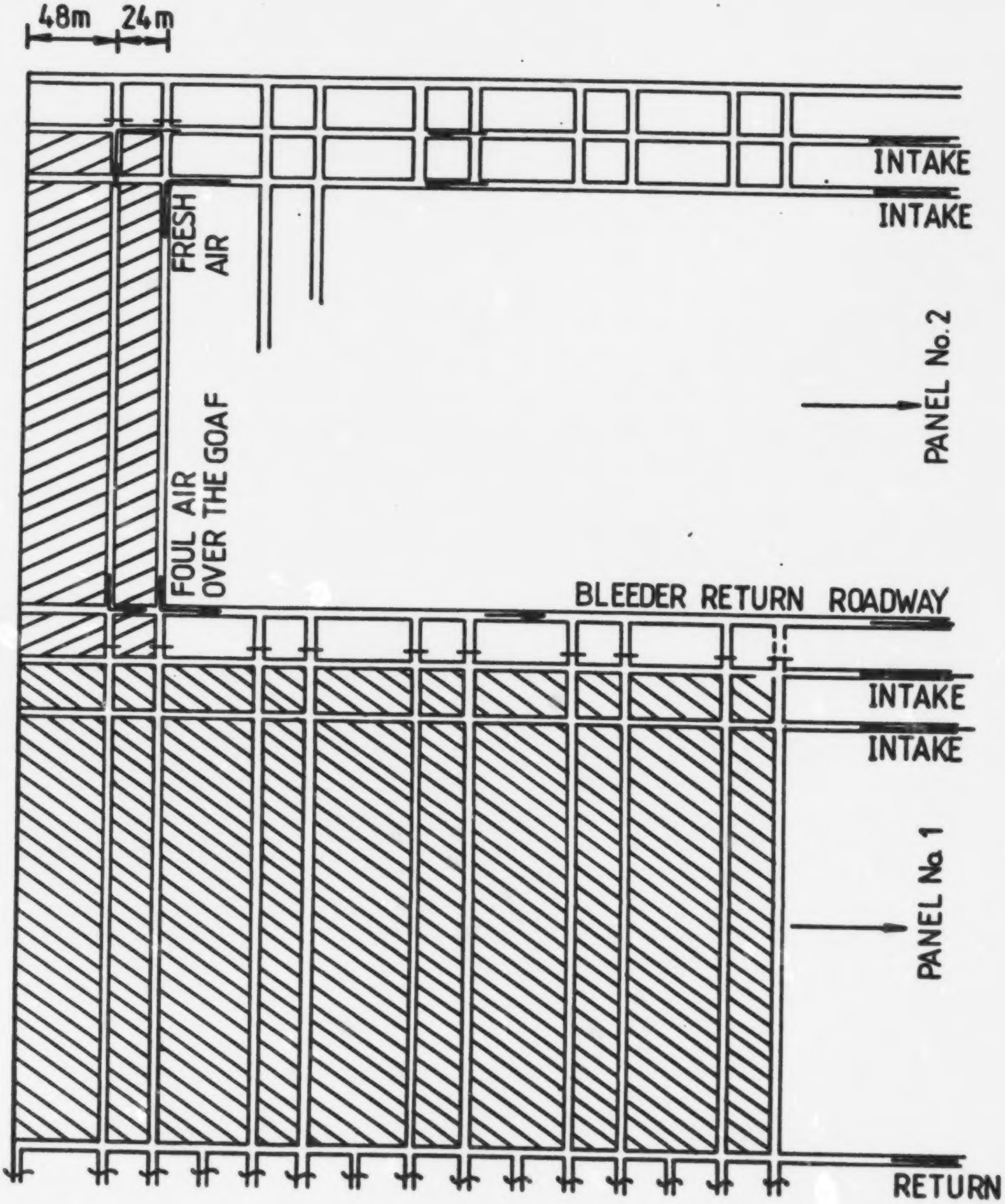

GOAF
COAL LEFT INSITU
1st. CUT
3,5m
BREAKER LINE FOR FIRST CUT
BREAKER LINE A
GOAF
2nd. CUT
3rd. CUT
4th. CUT
6,0 m
6,0m
5th. CUT
6th CUT
7th CUT
8th CUT
48m
1,8m (Length) ROOFBOLTS
0,5m
1,67m
0,5m
2,0m
BREAKER LINES
SECONDARY DEVELOPMENT

FIGURE 5

VENTILATION LAYOUT FOR THE DOUBLE CONTINUOUS MINER IN RIB PILLAR EXTRACTION


48m
24m
INTAKE
INTAKE
FRESH AIR
PANEL No. 2
FOUL AIR OVER THE GOAF
BLEEDER RETURN ROADWAY
INTAKE
INTAKE
PANEL No. 1
RETURN

COAL MINING

Old principle: new concept

DEREK HARVEY
Atlas Copco Canada Inc.

ABSTRACT

The paper briefly describes the development of the Eickhoff ESA60 roadcutter which is based on the old and well used principles of the shearer loader. It is intended to show that the machine offers a viable alternative to the normal methods used for driving roadways and also for coal production. References are made to installations currently operating in Europe with applications ranging from roadway drivage to pillar recovery. The paper also looks at possible applications in Canada.

Introduction

This paper is an attempt to show how the principles used in mechanical cutting, conveying and roof support are being applied to a development system capable of catering to a variety of situations and conditions. It is also intended to illustrate how the same system can be used as a total mining system for the mining of many minerals.

In order to give some sort of time perspective to the age of the principles, reference can be made to an article in Coal Mining & Processing which states:

— During World War II the Germans developed the "panzer" or armoured face conveyor.

— After the war the English developed power cutters or trepanners that were mounted on the face conveyor, this then developed into the shearer.

— The first shearer was produced by the Anderson Company in England in 1950 and shortly after that the Eickhoff Company started manufacturing shearers in Germany.

— The first hydraulic roof support was produced in 1954 by Gullick.

This is a potted history of the three major components of the new system, i.e.:

— Mechanical cutting element based on the shearer.

— Transport element based on the panzer.

— Optional roof support based on the hydraulic face supports.

It can therefore be said that since the "youngest" of the elements was produced in 1954 the principles of the system in respect of the rapid change in mining equipment are in fact old.

Of the three major components the most important is the cutting element since the major benefits of the system are to be obtained from this.

Development of the System

To appreciate why the system developed, it is necessary to look at the history once more and, in particular, at longwall faces in the early to mid-1960s.

A typical face was 200 m long and equipped with shearer, panzer and powered supports. There was, however, a bottleneck at either end of the face. This was the area where the shearer entered and was pushed forward to line the drum up for the next cut. These areas were known in England as stable holes and were very labour-intensive employing 4 or 5 men at the main gate end and 3 or 4 men at the tailgate end.

Not only were they very labour-intensive but the whole operation was out of step with the rest of the face since work in stable holes was basically unmechanized and strictly cyclic, and the face was mechanized and designed for continuous operation. As in all forms of mining there are variations, but a common cycle would have been:

— Undercut the coal using conventional cutters.

— Drill using handheld compressed air or electric borers.

— Charge and blast.

— Fill out using hand shovels.

— Support using manually set hydraulic props and steel bars.

It was quite common for the shearer to arrive at the stable hole and wait until room had been cleared to allow entry and pushing over into the new track.

As early as 1965, the Zolder Mine in Belgium, made attempts to solve these problems but at the same time avoid the drawbacks of the machines that were commercially available. There were two major drawbacks: high cost and difficult to adjust for level, direction and variation in seam height.

The Early Machines

The first machine was built by the Zolder mine at the mine site and tried in the excavation of a drivage in October 1966. A total of 150 m was excavated with an average of 2.70 m per shift and a maximum of 4.5 m per shift.

Derek Harvey

Derek Harvey, product manager, Mining Divison of Atlas Copco Canada Inc., joined the company in April 1982, and is currently in charge of all marketing for soft rock and coal mining equipment, including technology and machines from Atlas Copco - Eickhoff Engineering GmbH, Bochum, West Germany, and the Webster line of specialized loaders for coal mines.

His expertise in soft rock mining began in England and he gained his formal education at Doncaster College of Technology, and received a Higher National Diploma in mining engineering.

A decade of experience with the National Coal Board led to positions with Thyssen (GB) Ltd., and Atlas Copco (GB) Ltd., and most recently—prior to coming to Canada—as director of sales, and a member of the board of directors of Markham (Sheffield) Ltd.

Mr. Harvey is a Chartered Engineer, and is a member of the Institution of Mining Engineers.

Keywords: Coal mining, Shearer loaders, Roadcutters, Roadway drivage, Pillar recovery, Mechanical cutting, Conveying, Roof supports.

Paper reviewed and approved for publication by the Coal Division of CIM.

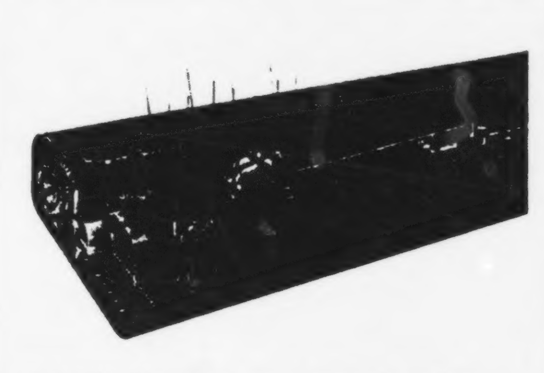


FIGURE 1. ESA 60 with powered supports for drivage an arched roadway.

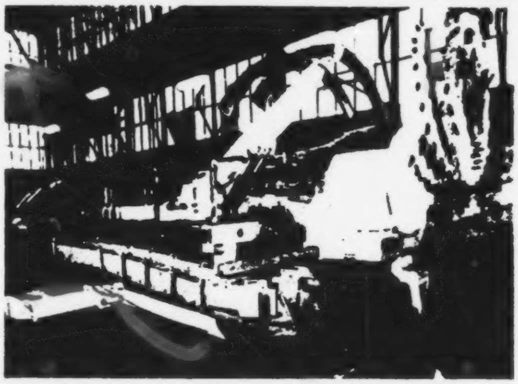


FIGURE 2. ESA 60 with arch setting device.

Improvements were made to the prototype and two further trials were made of 160 m and 140 m in early 1967. These test drits were excavated following the slope of the seam and with a width of 3.6 m. Average advance was 14.5 m per day.

Following the tests, the installation was extended to 8 m and used on a longwall face where advances of 2.4 m per shift were obtained. These early machines had the capability to operate on widths between 4 m and 8 m.

The machine itself consisted of a small cutting drum entrained along the face by means of a winch with a towing chain. The coal was transported on a curved flight conveyor, curving 90 degrees at one end followed eventually by a second curve of 45 degrees.

The conveyor and cutting machine were advanced by pushing forward with hydraulic cylinders. Cutting level and direction adjustment were provided by hydraulic jacks. The roof support system was provided by props and bars to fit into the existing mine support system.

On the first machines, the cutting drum was hydraulically driven, the pump unit being separated from the machine and advanced with the power packs from the longwall.

The major dimensions and brief technical specification of the machine were:

Drum diameter	1200	mm
Drum thickness	120	mm
Rotation speed	80	rpm
Peripheral speed of cutters	5.02	m/sec.
Power	27	kW
Travel speed	0.5	m/min.
Maximum torque	500	kgm

Experience showed that although significant advances had been made there were still weak points. These were:

— The machines had hydraulic drives leading to—
  Security problems since the hoses were long and filled with high pressure oil.
  Heat generation leading to lower performance
  High oil consumption

— The cutting height was limited by the drum diameter and variations required additional mining with pneumatic picks which led to lost time.

— The productivity of the machine was too low in hard ground.

— Mechanical availability was too low when conditions were difficult. An excellent maintenance crew was essential.

— The travel speed was limited to 1.5 metres per minute which was found to be too low.

— The chain drive haulage system had all the built-in inconveniences experienced with longwall installations.

— The scraper conveyor had low availability and life.

In order to eliminate these problems the mine management collaborated with the German shearer manufacturer Eickhoff. By utilizing the known results and experiences from the mine and the expertise of Eickhoff a new machine was developed.

The New Machines

The new Eickhoff machine was designated the ESA60 and had the following basic specifications:

Drum diameter	1700	mm
Drum thickness	400	mm
Rotation speed	32	rpm
Peripheral speed of cutters	2.68	m/sec.
Power	63	kW
Maximum torque	4000	kgm
Travel speed	0.3	m/min.

The resulting machine eliminated the majority of the weak points of the original machines, e.g.:

— Electric drive to the drum.

— Water sprays integrated into the drum.

— New, more reliable conveyor system.

It must be pointed out, however, that in removing the weaker points of the original machine, two inconveniences appeared:

— The over-all height was increased from 1170 mm to 1300 mm.

— The available room over the machine in the conditions at the mine was reduced from 340 mm to 280 mm.

These inconveniences however are minimal when set against the new possibilities of increased cutting heights. The increase in over-all height was inevitable since it is impossible to build a mechanical machine of this type any smaller.

The machine was tried in heading development at various locations and for this use the length of the conveyor was reduced to 4 m or 5.5 m. Three headings were driven at Zolder between 1966 and 1967. In all 450 m were driven with a maximum shift advance of 7 m. Fifteen headings were driven from 1976 at Zolder and two neighbouring mines—in all 3,279 m were driven with a maximum daily advance in two shifts of 24 m.

The problem of the fixed cutting height which slowed the machine and limited its use, therefore further design was undertaken and a ranging arm added still existed. This arm was made available in three sizes which when used with the various drum diameter options gave a machine the capability of cutting from 1900 mm to 3200 mm.

This is the machine as it is today, i.e.:

Motor power	60 kW
Cutting depth	420 - 625 mm
Travelling speed	1 - 6 m/min.
Machine length	1500 - 2100 mm
Machine height	1285 - 1935 mm
Total weight (approx.)	5.5 - 9 tonnes

Drum Diameter	Length of Ranging Arms		
	250	500	7500
1400	1900	2400	2900
1500	2000	2500	3000
1600	2100	2600	3100
1700	2200	2700	3200
	Maximum Face (mm)		

TABLE 1. Reference list of ESA roadcutters

Country	Colliery	No.	Ranging Arm	Drum	M/c Height	Cutting Height	Undercut	Conveyor	Application
ESA-60-L									
Belgium	Zolder	10	250	o 1700 x 420	1435	1700 - 2200	0	EKF-0	1*
	Wintersiag	2	250	o 1700 x 420					
	Beringen	2	250	o 1700 x 420					
	Eisden	3	250	o 1700 x 420					
	Zolder	1							
	Beringen	1	500	o 1600 x 650					
	Zolder	1	750	o 1600 x 650					2*
	Waterschei	1	750	o 1700 x 650					2*
	Zolder	1	750	o 1700 x 515					2*
	Zolder	1	750	o 1800 x 420	1985	3300	0	EKF-0	3*
Germany	Walsum	1	250	o 1400 x 420	1285	1400 - 1900	0	EKF-0	4*
	PREAG	1	750	o 1600 x 625	1685	2900	200	EKF-2	5*
	Osterfeld	1	250	o 1400 x 420	1185	1400 - 1780	120	EKF-0	4*
	Lohberg	1	500	o 1400 x 420	1535	1700 - 2400	0	EKF-0	4*
	Pattberg	1	250	o 1400 x 420	1185	1400 - 1780	120	EKF-0	4*
France	Carmaux		750	o 1600 x 515	1585	3150	max. 300	EKF-0	5*
Yugoslavia	Trbovlje	2	750	o 1600 x 625	1735	2950	150	EKF-2	5*
Hungary	Pecz	1	750	o 1400 x 625	1485	2600	300	EKF-2	5*
Australia	Sydney	1	750	o 1600 x 625	1885	3100		EKF-0	4*
ESA-60-K									
Belgium	Zolder	2	750	o 1600 x 420	1330	2545 - 3620	555	EKF-2 EKF-0	2* 3*
ESA-60									
Germany	Ewald	1	250	o 1700 x 420	1300	1700	0	EKF-0	4*
ESA-150-L									
Yugoslavia	Velenje	1	1335	o 1600 x 750	1502	3237	max. 460	EKF-3	5*
Czechoslovakia	Novacky	1	1335	o 1600 x 750	1550	3285	max. 440	EKF-2	5*
ESA-150-K									
Belgium	Zolder	1	1600	o 1600 x 800	1600	3550 - 4200	1280	EKF-0	3*

1* Stablehole machine
2* Face-end machine
3* In-seam roadheader
4* Face opening machine
5* Shortwall face shearer

Current Installations

At present, the supply of ESA60 machines has been limited to Europe, however, they are not all limited to stablehole machines (Table 1).

The New Concept

It has become quite obvious from the experiences gained in Europe with the varying installations and of what is feasible from the machine that it is far more than a stable hole machine.

We now have available a machine and system capable of total mining of coal or other soft rock minerals. The new concept is to utilize longwall techniques for high speed drivage and by extending the conveyor and increasing the powered supports use the same machine for production.

The concept can have many variations but will, in fact, be limited only when mining engineers stop being so ingenious.

In order to try to explain the system, it is easier to consider the operation as two separate entities, development and production.

Development

Although for the purposes of the explanation of the system as a drivage method the output is not considered to be the main production, however, it is in fact quite considerable.

The system is basically arranged as shown in Figure 1 with the number of powered supports depending on the width of the heading and the type of support chosen. The configuration of the tail conveyor is variable as is the length depending on the method of conveying from the face.

The operation of the system is simple. The machine wedges itself into the face and cuts from zero to full drum width. The conveyor is pushed forward using the horizontal cylinders of the powered support. The process is then repeated as a mirror image of the first cut. The conveyor is then advanced again until the full extent of the cylinders is reached. The powered supports are then brought forward in the same manner as longwall supports. It must be emphasized that there is no reason whatsoever to stop the support from being advanced after each cut. This is especially advantageous in weak roof conditions because support can be applied almost immediately after the coal has been cut.

For other minerals where roof support is not a problem and it has been found that the roof is strong, the powered supports can be substituted by stells with pushing rams attached.

Production

For production it is envisaged that the same cutting machine is used and that the conveyor is extended and additional roof supports added. The basis of the system is to develop the mine into short width panels of 40 m to 50 m in width with a face line (panel length) as long as possible. The conveyor is left in the same position, i.e. with the tail conveyor extending outbye, but the machine is turned to face the opposite way. A short longwall situation has now been created and with it all the inherent benefits of retreat longwall operation.

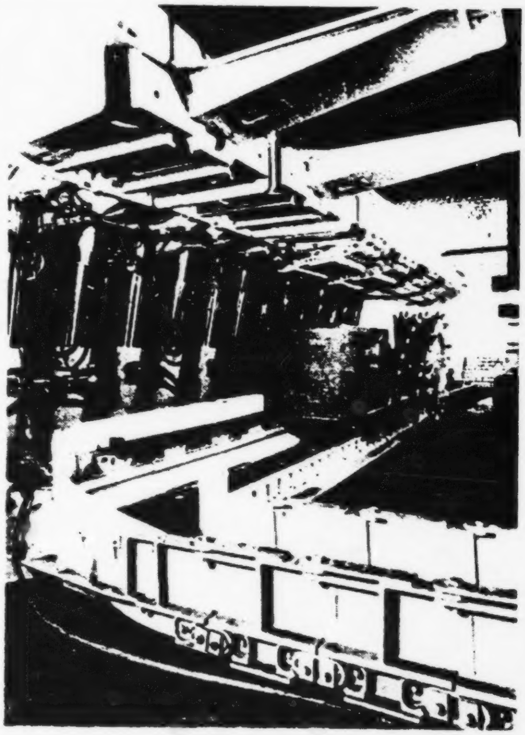


FIGURE 3. ESA 60-layout for pillar extraction.

Permanent Roadway Support Facilities

One of the important features of the design is to be able to set permanent roof supports in very close proximity to the face. This gives rapid support, reduces the amount of open ground and adds to operator safety.

Because the support system must fit into the existing schedule of permanent support already in the mine, any new system must have the flexibility to also adapt. The new system caters to the majority of support types including: roof bolts, arches and straight girders.

Roof Bolts

Because powered supports are used the newly cut roadway section is supported immediately over the machine and depending on the over-all length of the roof canopy up to about 4 m behind. By utilizing a variable position roof bolting system attached to each powered support, bolts can be installed either between the powered supports or directly behind ensuring excellent roof control. The setting of the bolts can be done during the cutting operation thus eliminating downtime.

Arches

Arches can be set either at the front of the powered supports and directly behind the face conveyor or directly behind the powered support. In either case a modified powered support canopy is used to lift the arch and hold it in position until it is strutted and covered.

Straight Girders

Straight girders can be set in a similar fashion to arches, the legs whether steel, temporary hydraulic or wood can be set at the side of the powered supports. For installations where no powered supports are used or where arches or girders are set directly behind the supports a separate arch setting device can be used (Fig. 2).

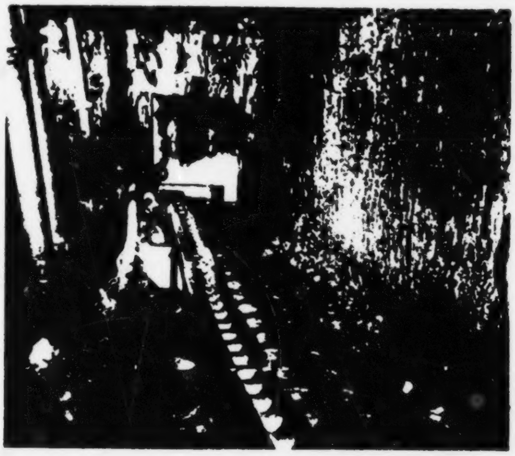


FIGURE 4. ESA 60 in an advanced heading.

Possible Applications in Canada

Coal

Whether the mine is a new mine or an existing mine there is scope for the use of the system. The system offers an alternative method for working.

Single Entry Mining

A system tried in England, single entry mining offers a different method of mining which is capable of relatively high outputs but has lower cost than conventional systems. It can and has been used in the partial mining of pillars of coal without destroying the support properties of the pillars.

In principle one entry is driven as far as practicable, then turned through 90 degrees and a cutting machine installed. The extraction is done on the retreat and face lengths can be up to 40 m or 50 m. The ESA system is ideal since the machine can be used to drive the roadway, turn through 90 degrees, drive the face line and then be used as a mini-shearer.

Because the face has a "blind end", ventilation has to be produced by direct and auxiliary fans and careful monitoring is recommended.

Pillar Recovery

The system offers a method of pillar recovery whether the mine has been laid out for room-and-pillar mining or whether the pillars are existing ones (Fig. 3). The equipment is arranged as a mini-longwall and retreated thus giving high output rates.

Steep Seam Mining

The capability of the system to operate on steep gradients both in inclines and cross grades opens up new possibilities especially in western Canada.

The system can operate on cross grades of up to 45 degrees by the addition of a secondary haulage system. The maximum incline is also about 45 degrees, and it is also possible to operate the system on an incline with cross grade of 13 - 14 degrees. This allows the mining of seams which have previously been thought to be too steep to mine. The system allows not only the development to be done but also short longwall production workings.

Mining Areas of Varying Thickness

By using the ranging arm and the various drums, seam thicknesses of 1.9 m to 3.2 m can be mined. This will allow the economical and profitable mining of areas of coal which vary in thickness over the property. For many years thinner seams have been mined in Europe as easily, and in many cases, more easily than thicker seams. Now a system is available to allow mining of both thin and thick seams with the same machinery at the same mine.

Other Minerals

In the category of other minerals, as a rule of thumb guide, any material with a rock strength of 10,000 psi can be mined using this system. Although this is one method of measurement, obviously criteria such as tensile strength and abrasiveness must be taken into account. Again as a rule of thumb, minerals such as potash, gypsum, salt, etc. can be mined.

Basically, all the comments that apply to coal apply to these minerals, however, there are certain additional uses of interest at these mines.

Top Heading and Bench

In extremely thick deposits it is common to mine by driving a top heading and benching, because the machine can mine up to 40 m - 50 m wide with a height of 3.2 m (Fig. 4). The system can be used to drive the top heading and offers the opportunity (where conditions allow) to drive a heading of, say, 10 m to 20 m wide by 3 m high. This not only gives a production rate of 2 tonnes per minute from the development but allows a larger bench to be taken.

Thick Deposits

As an alternative to top heading and benching, the original heading is driven forward as fast as possible. The system is withdrawn after the required length of heading has been driven, reinstalled at the start of the heading to take out the next 3 m down. The drivage sequence can then be repeated.

Conclusion

At the start of this paper it was said that the purpose was to give a very brief description of the development, current use and future of a new concept of mining. The development arose out of a need, the solution was the use of the old principle of the shearer and the new concept is a drivage and production system.

To summarize, we now have a high speed versatile system for mining of coal and soft rock deposits.

The object of the paper has been to promote discussion and possibly give some basic ideas that could help make coal mining more efficient and safer, while offering production at a lower cost.

ACIRL
COAL RESEARCH

Australian Coal Industry Research Laboratories Ltd.

GEOTECHNICAL EVALUATION OF WONGAWILLI EXTRACTION SYSTEM AT COALCLIFF COLLIERY

BY

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SUMMARY

A research program is being conducted by Australian Coal Industry Research Laboratories Ltd (ACIRL) to evaluate the parameters affecting pillar stability, the main aim being to determine appropriate pillar development and extraction methods relative to conditions existing in underground coal mines. Coalcliff Colliery is one of several locations of differing strata characteristics, chosen for the program. The data obtained from Coalcliff and the other locations still to be researched will give a broad understanding of the problems of pillar instability and aid in the planning of pillar extraction panels in future coal mining environments.

This report details the results obtained at Coalcliff Colliery 227 Panel between 8 and 9 cut-throughs. These results are related to the Wongawilli system of coal extraction.

The work carried out at Coalcliff included the installation of extensometers and stress cells in the ribs of pillars to be extracted, in the solid extraction block and also into the roof of adjacent roadways. Monitoring of the above equipment showed that the stresses did not change greatly during the development or initial extraction of the pillars. A pronounced stress change was noted when the extraction line was within 60 m of the installation site. Whilst the stress cells recorded the above information, the extensometer installed in the ribs and the roof showed less deformation in the pillars and roof.

The only problems or deterioration in conditions were the flaking of the roof strata, the guttering of this strata along the rib lines and the spalling of the ribs in a number of locations.

For the existing conditions, the pillars initially developed with a width of 18 m, had a solid core of 9 m width during the extraction cycle. The results and visual observations showed that the peripheral rib areas around the pillar were yielding and crushing. The adjacent solid coal block was slightly crushed along the rib line; however the deformation in no way compared to that of the pillar under extraction.

The results obtained from this and future monitoring programs, together with coal strength and deformational characteristics, will also be used to develop appropriate Australian pillar design criteria.

Mathematical modelling in the form of the ACIRL developed program THREED, is also being utilised to correlate both the underground monitoring and empirical methods used in forecasting pillar stability.

The THREED program provides plots of the distribution of stress, yielded coal and roof to floor convergence and has the distinct advantage that a number of panel layouts and virgin stress changes can be easily modelled.

1. INTRODUCTION

A project of evaluating pillar stability and extraction methods, undertaken by ACIRL, has an objective of determining parameters which affect the choice and performance of both development and extraction methods of bord and pillar operations, with a view to determining optimum development panel layouts and extraction methods for mining at greater depths.

Through monitoring of instrumentation while pillars are being extracted, the following benefits are expected:

1. Demonstration that the fendering method provides a destressed mining environment to the advantage of the extraction system.
2. Knowledge of stress increases in coal pillars in relation to the mining sequence and strata conditions.
3. Knowledge of roof and pillar deformation in relation to the mining sequence and strata conditions.
4. Use of the above information to enable safe pillar design procedures and selection of the most appropriate pillar extraction system for a given set of strata conditions.
5. Geomechanical properties obtained from core testing and the information gained earlier are being used to conduct mathematical modelling to determine the optimum dimensions of pillar panel sizes and layouts for new coal mining areas.

Coalcliff Colliery situated on the south coast coalfields of New South Wales, mines the Bulli seam to a full seam height of approximately 2.7 m. The Wongawilli pillar extraction system was first introduced to Australian mines 15 years ago and has since been gradually modified to suit both the mining conditions and development of mining machinery. This extraction method has proven to be a successful mining practice due to the high percentage extraction obtained (80-90%), improved worker safety, minimal required development workings, and high rates of production achieved.

ACIRL chose the site at Coalcliff Colliery as being typical of Wongawilli extraction panels, working under massive sandstone conditions. The information collected would not only produce a measure of the success and suitability of the Wongawilli method which is used at the colliery but also provide valuable data to assist in improving the design of future Wongawilli extraction panel layouts.

2. GEOMECHANICAL AND MINING ENVIRONMENT

Coalcliff Colliery mines the full 2.7 m thickness of the Bulli Seam. The depth of cover to the mine workings is approximately 480 m. Roof geology at the colliery, and in particular the area investigated, varies from a laminated mudstone (total thickness of 0.4 m to 1.8 m) through to a layered to massive sandstone (total thickness of 10 m) as shown in Figure 1. Whilst the immediate roof strata varies, it can be seen in Figure 2 that the strata immediately overlying the mudstone/shale is a sandstone.

The immediate roof strata in the area investigated, i.e. 227 Panel, is mudstone. Panels under the mudstone roof were two heading development whilst the panel under the sandstone roof was a three heading development.

Two heading development was considered under the mudstone roof, the major advantage being the resultant stable roof conditions which of course required less maintenance. It had been found in 226 Panel, a three heading development, that the roof conditions were very unstable and required more maintenance and roof support.

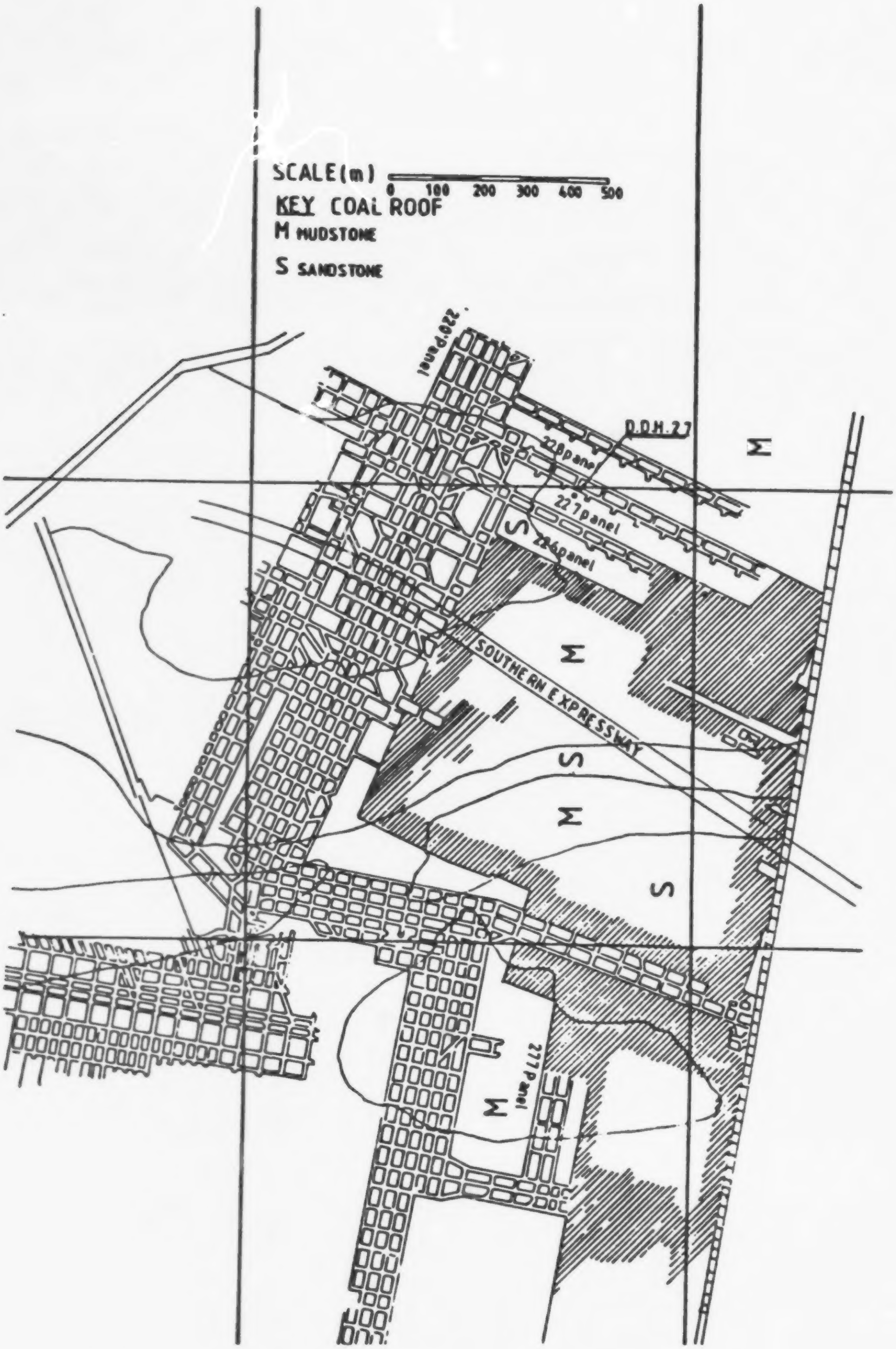

SCALE(m)
0 100 200 300 400 500
KEY COAL ROOF
M MUDSTONE
S SANDSTONE
220 Panel
D.D.H.27
228 panel
227 panel
226 panel
SOUTHERN EXPRESSWAY
M
S
M
S
M
S
M
217 Panel
M

Figure 1. Coalcliff Mine Plan.

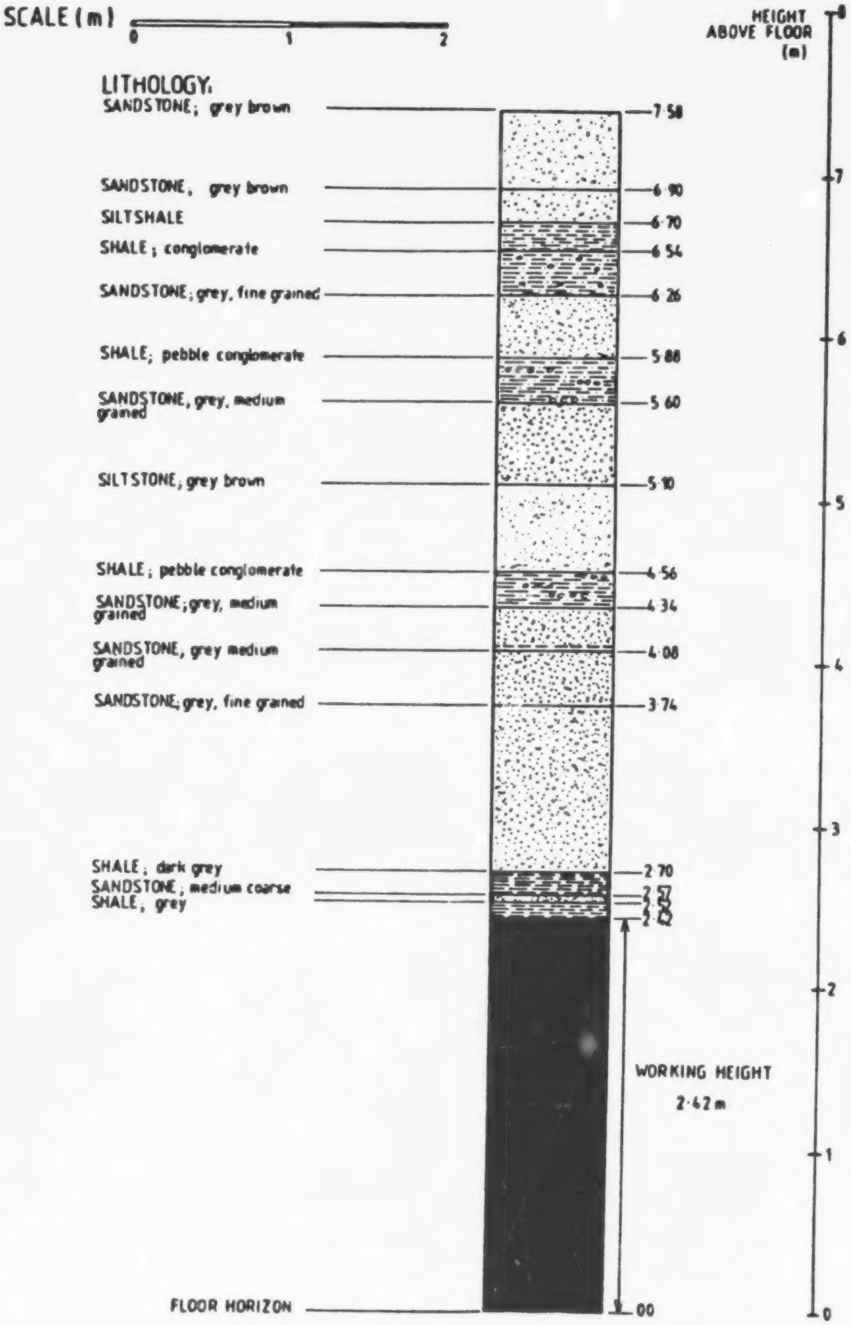

SCALE (m)
0
1
2
HEIGHT ABOVE FLOOR (m)
LITHOLOGY:
SANDSTONE; grey brown
SANDSTONE, grey brown
SILTSHALE
SHALE; conglomerate
SANDSTONE; grey, fine grained
SHALE; pebble conglomerate
SANDSTONE, grey, medium grained
SILTSTONE; grey brown
SHALE; pebble conglomerate
SANDSTONE; grey, medium grained
SANDSTONE, grey medium grained
SANDSTONE; grey, fine grained
SHALE; dark grey
SANDSTONE; medium coarse
SHALE; grey
FLOOR HORIZON
7·58
6·90
6·70
6·54
6·26
5·88
5·60
5·10
4·56
4·34
4·08
3·74
2·70
2·57
2·52
2·42
00
WORKING HEIGHT
2·42 m
8
7
6
5
4
3
2
1
0

Figure 2. Geological Cross Section of Roof Strata.

3. DESCRIPTION OF THE MINING CYCLE FOR THE WONGAWILLI SYSTEM OF PILLAR EXTRACTION IN 227 PANEL

3.1 PILLAR DEVELOPMENT

The Wongawilli system involves a small amount of development isolating a large block of coal on one side, as shown in Figure 3. The number of entries for panel development at Coalcliff Colliery is dependent on roof strata formation of the particular panel to be developed, as mentioned earlier. Machinery used for panel development at the colliery consisted of two shuttle cars and a continuous miner.

227 Panel was developed by two heading development, air return and belt and track headings. The development commences by mining the return heading 5.5 m wide to a length of 62.5 m (see Figure 4a). The continuous miner is then pulled back to develop the belt and track heading 6.5 m wide (see Figure 4b). The return and the newly formed belt and track headings are connected together by 5.5 m wide cut-throughs to form 62.5 m x 24.0 m pillar centres. During the development of the belt and track heading, car shunts are cut adjacent to the inbye end of each pillar to improve shuttle car wheeling lines. The belt is extended in stages of full pillar length from A to B. This gives the maximum wheeling distance of 120 m for the shuttle car. The face was ventilated on brattice, and pillar lengths of 62.5 m were chosen under mudstone to minimise intersections and provide adequate face ventilation. The pillar width of only 24 m was selected because the cut-throughs were driven in the worst mining direction, and a short cut-through length minimised any mudstone roof problems. The development cycle has been planned so that production is carried out on four shifts and belt extension or retraction is carried out by a permanent belt crew.

The roof exposed during development is immediately supported. The support varies dependent upon the locations or the area being mined. Such support is as follows:

a) In the belt and track heading, 6.0 m long W straps, set at 1.2 m intervals with 7 rock bolts in each strap.

b) In the return and cut-throughs, 5.0 m long W straps bolted to the roof with 4 rock bolts per strap.

The rock bolts of mild steel are 2400 mm long. They are anchored into the main roof using 25 mm x 440 mm long resin capsules. The roof support pattern is shown in Figure 5.

A laser beam is used for direction control during development.

Men and materials are transported to the working place by rail, while the coal produced is transported from the face to an underground coal bin by a 1050 mm wide conveyor belt.

3.2 PILLAR EXTRACTION

Coal extraction commenced with roadways or splits being driven off the belt-track heading into the block of coal, as shown in Figure 3. In 227 Panel the split direction was chosen so that it would not be running at right angles to the cleat. This was based on a comparison with the adjacent 226 Panel. A definite but marginal improvement was achieved in the control of the immediate mudstone roof strata. A second roadway or split at 12.5 m centre was driven into the block parallel to the first to form a "fender". This "fender" was then extracted by successive lifts, the only coal remaining being that left in the stooks (see Figure 6). Each pillar was extracted using 5 splits.

The splits were supported by half round timber bars bolted to the roof and additionally supported at either end by a prop. No support was required in the lift as the continuous miner driver was protected by the support in the split.

With reference to Figure 3, the belt was retracted in half pillar lengths, e.g. from A to B, when the continuous miner had extracted two splits and the respective fenders. The second half of belt retraction was to C position when the continuous miner extracted off the last split.

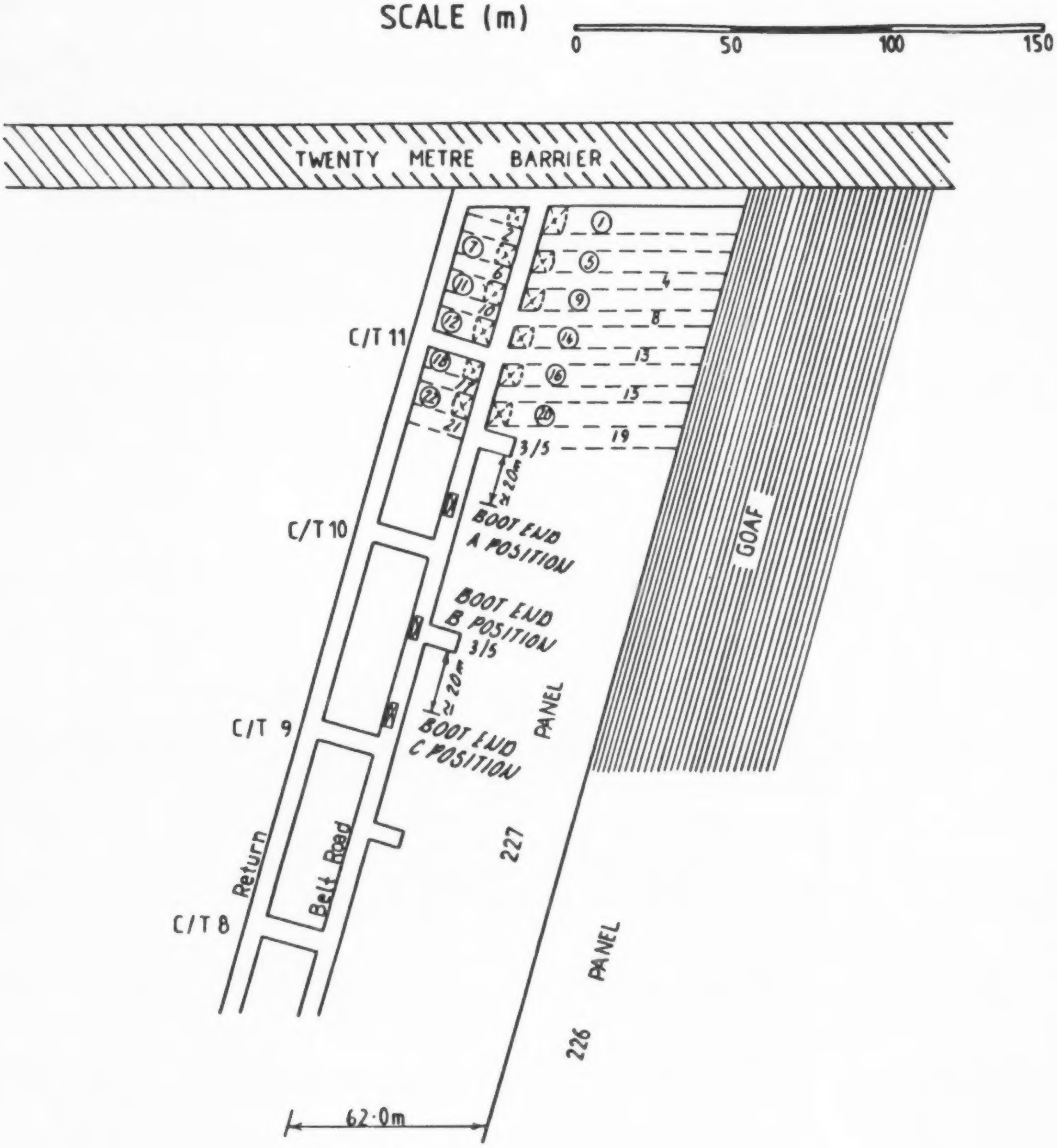

SCALE (m)
0
50
100
150
TWENTY METRE BARRIER
①
2
⑤
⑦
4
6
⑨
⑪
10
⑫
8
⑭
13
C/T 11
⑱
17
⑯
15
㉒
⑳
21
19
3/5
≈20m
BOOT END
A POSITION
GOAF
C/T 10
BOOT END
B POSITION
3/5
≈20m
C/T 9
BOOT END
C POSITION
PANEL
227
Return
Belt Road
C/T 8
PANEL
226
62·0m

Figure 3. Plan showing Proposed Sequence of Pillar Extraction and Belt Moves in 227 Panel

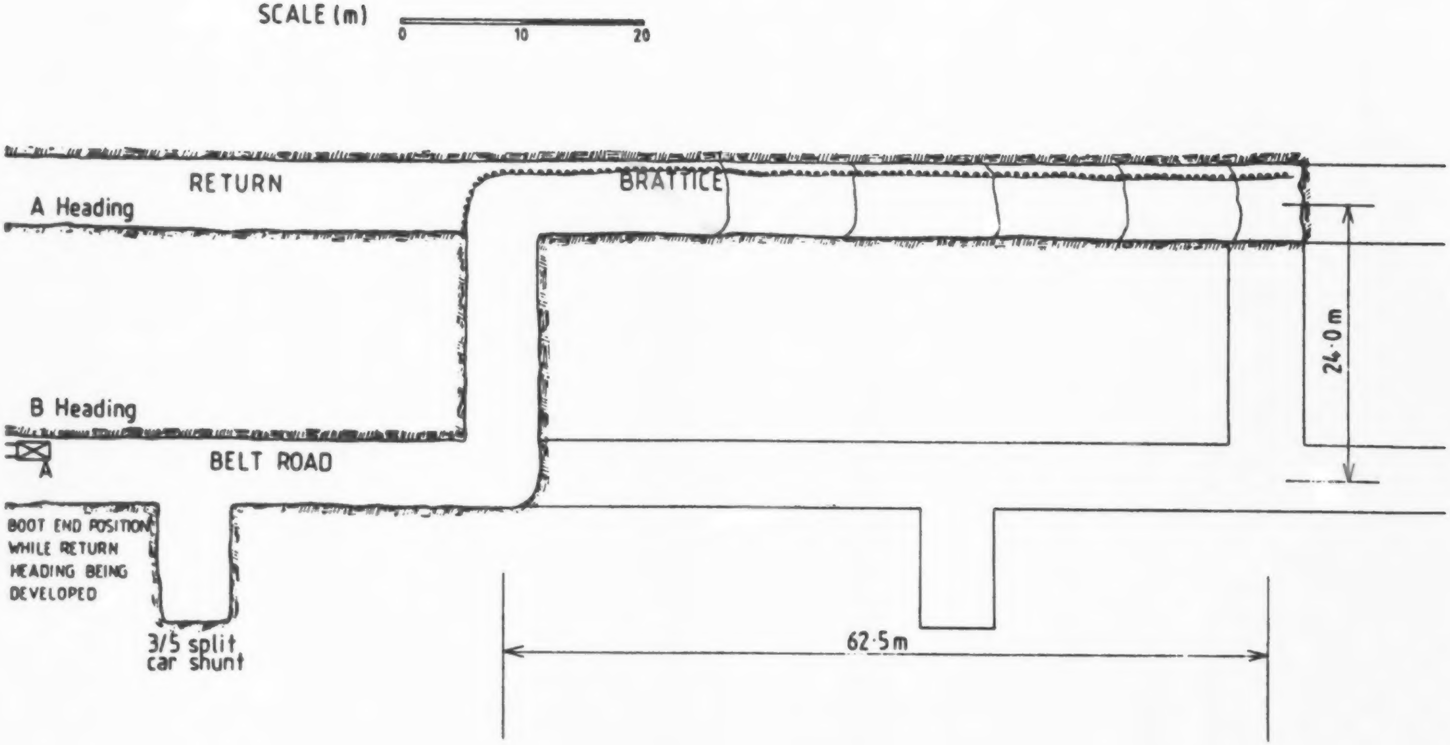

SCALE (m)
0
10
20
RETURN
A Heading
BRATTICE
B Heading
BELT ROAD
A
BOOT END POSITION WHILE RETURN HEADING BEING DEVELOPED
3/5 split car shunt
24·0 m
62·5 m

Figure 4 (a) - Panel Development
(a) - Boot end Position during the Return Heading Development.

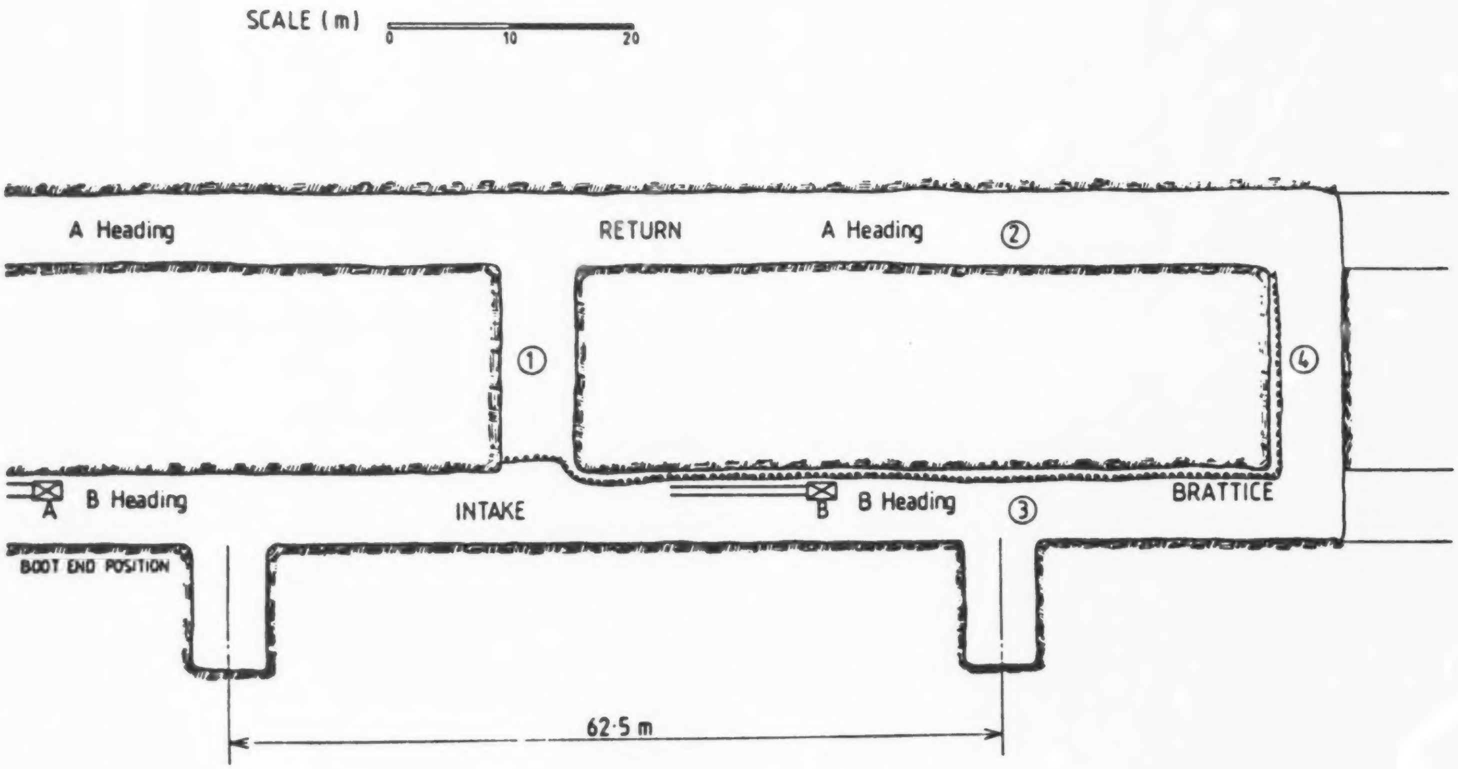

SCALE (m)
0
10
20
A Heading
RETURN
A Heading
②
①
④
B Heading
A
INTAKE
B
B Heading
③
BRATTICE
BOOT END POSITION
62·5 m

Figure 4 (b) Panel Development
(b) - Boot End Positions during Belt Heading and cut-throughs.

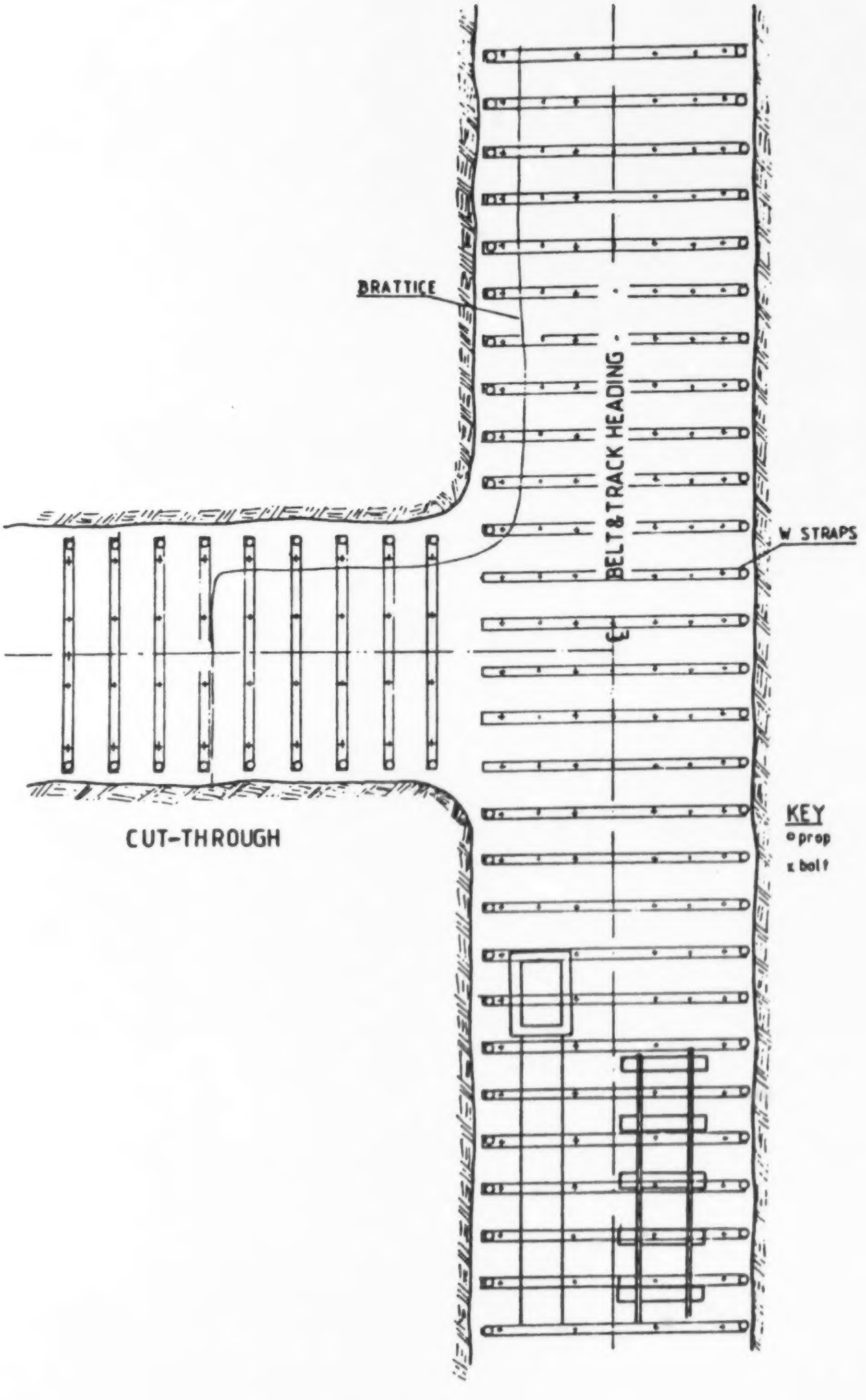

BRATTICE
BELT&TRACK HEADING
℄
W STRAPS
CUT-THROUGH
KEY
○ prop
x bolt

Figure 5. Roof Support System at Coalcliff Colliery.

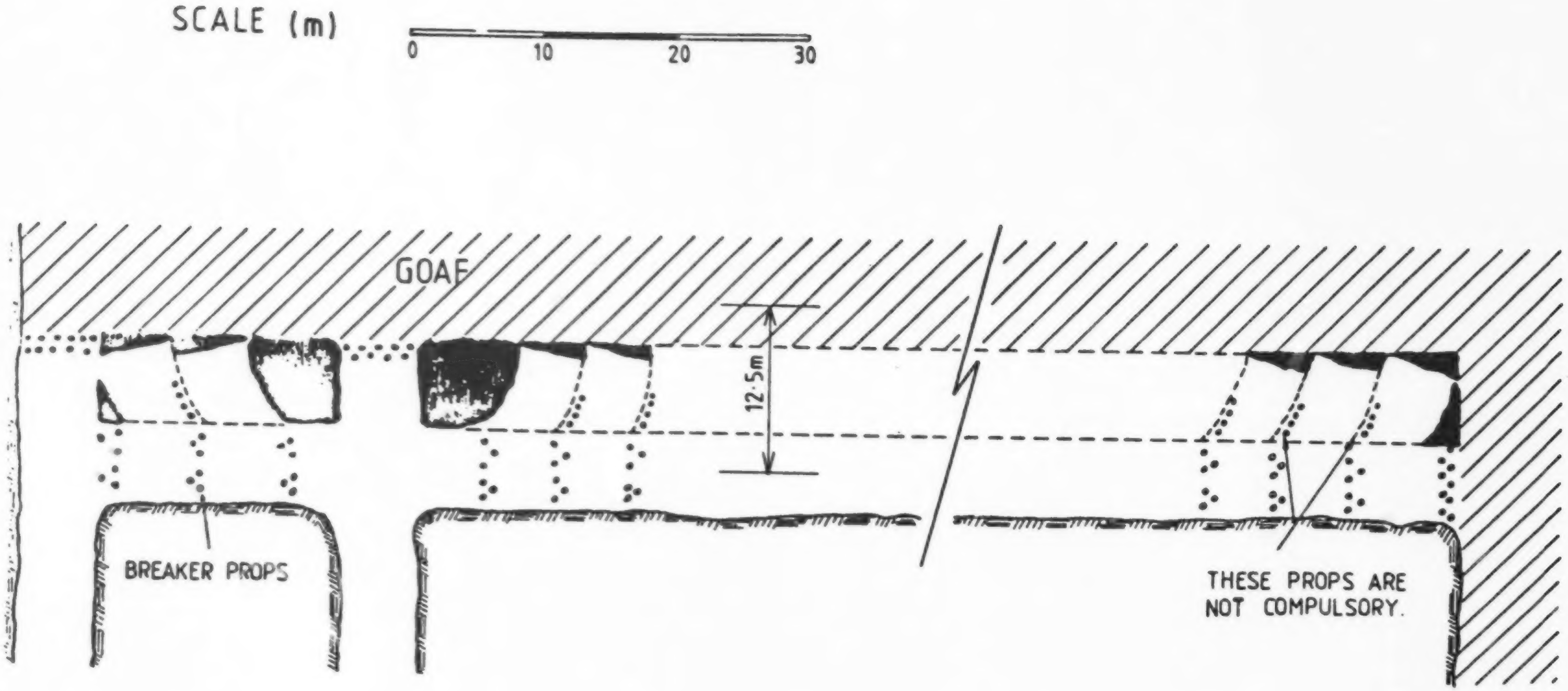

SCALE (m)
0
10
20
30
GOAF
12·5m
BREAKER PROPS
THESE PROPS ARE NOT COMPULSORY.

Figure 6. - Detail Plan of Fender Extraction Method, showing the Position of Breaker Props when Lifting off.

4. INSTRUMENTATION LAYOUT FOR THE PROPOSED MEASUREMENT

During pillar extraction the roof and pillar adjacent to the working came under increasing vertical and horizontal stresses, causing deformation. Strains were measured using roof and rib extensometers, and stresses were measured using roof and rib extensometers, and stress cells respectively. Figure 7 shows a plan of the monitoring equipment installed.

4.1 MEASUREMENT OF DEFORMATION

Roof Extensometer

This system measures differential roof deformation in the direction of the borehole and indicates position and magnitude of roof separation with respect to time and mining sequence.

A multiple position borehole extensometer is used. A maximum number of four expansion shell extensometers are installed in one hole. Strata movement at all anchor points is transmitted to the collar of the hole by thin stainless steel wires, where either the relative movement between anchors or the absolute movement for each expansion shell is monitored by a calibrated dial gauge.

Rib Pillar Extensometer

A pillar is supposedly divided into two zones, a central inner core, surrounded by a yielding zone which contains the inner core. To determine the stability of the pillars, rib extensometers are installed in pillars to measure the amount of movement taking place in the coal at various depths. Zones where no movement takes place are considered to be "solid", while zones which are moving are considered to be yielding. The development of the zones of yielding coal towards the centre of the pillar with the progress of time indicates whether the pillar will remain stable for a long period of time.

4.2 MEASUREMENT OF STRESSES

Vibrating Wire Stressmeter

The IRAD vibrating stressmeter is designed to monitor stress changes in rock, coal or concrete under the most adverse environmental conditions. When prestressed into a 37 mm borehole, the cylindrical gauge can sense stress changes as little as 14 kPa (2 psi), so this instrument is used to quantify the increase/decrease in applied stresses to coal pillars and roadway roof strata with respect to the time and mining sequence.

5. ANALYSIS OF RESULTS

5.1 MINING INDUCED STRESSES

Two sets of measurements were carried out across the pillar and in the coal extraction block formed between 7 and 8 cut-throughs, as shown in Figure 7.

The IRAD vibrating wire stress cells used only measured stress changes in one direction depending on their orientation. For the purpose of this investigation at Coalcliff Colliery all stress cells were positioned in a way which enabled them to monitor changes in the vertical stress.

The results were presented in graphical form showing the stress change against time and face position for each cell installed. Figures 8 and 9 show the relationship between the change in stress relative to the pillar and the solid block extraction cycles respectively. The results of the stress cell (S_1) positioned in the solid extraction block indicated no increase in stress during the development stage of the panel until a goaf 30 m wide was formed, as shown in Figure 8. A gradual increase of 4 MPa was recorded while extraction of coal took place 250 m to 58 m away from Site 1. The characteristics can be designated as the forward abutment stress of approaching goaf. Once the goaf was within 58 m of the installation site a rapid increase in stress of 7 MPa was recorded. This characteristic can be designated as the immediate abutment buildup. Unfortunately this stress could not be monitored to the completion of the mining sequence. If it had the stress would have been similar to that obtained from stress cell (S_3) and would have reached a value of approximately 24 MPa, see Figure 9. Once the stress reached a peak, there was a rapid decrease due to stress being transferred into the adjacent unmined solid coal. At this point the fender being mined was in a destressed zone where the pressure dropped to a low level of stress between 8-4 MPa.

5.2 SUMMARY OF STRESS AND CAVING CONDITIONS

As mentioned previously, the roof strata in 227 Panel consists of an immediate roof layer of friable mudstone up to the thickness of 1.8 m. Above this material competent sandstone is found. This type of roof strata allied with the stress environment will determine the caving characteristics.

The caving conditions and stress environment are shown in Figure 11 and in Plate 1. Plate 1 is a photo taken in the return heading (A Heading) looking into the goaf. It can be seen that the unsupported sandstone roof 20-30 m in length was sagging in the form of a cantilever. Further into the goaf, large blocks of sandstone had collapsed consolidating the goaf.

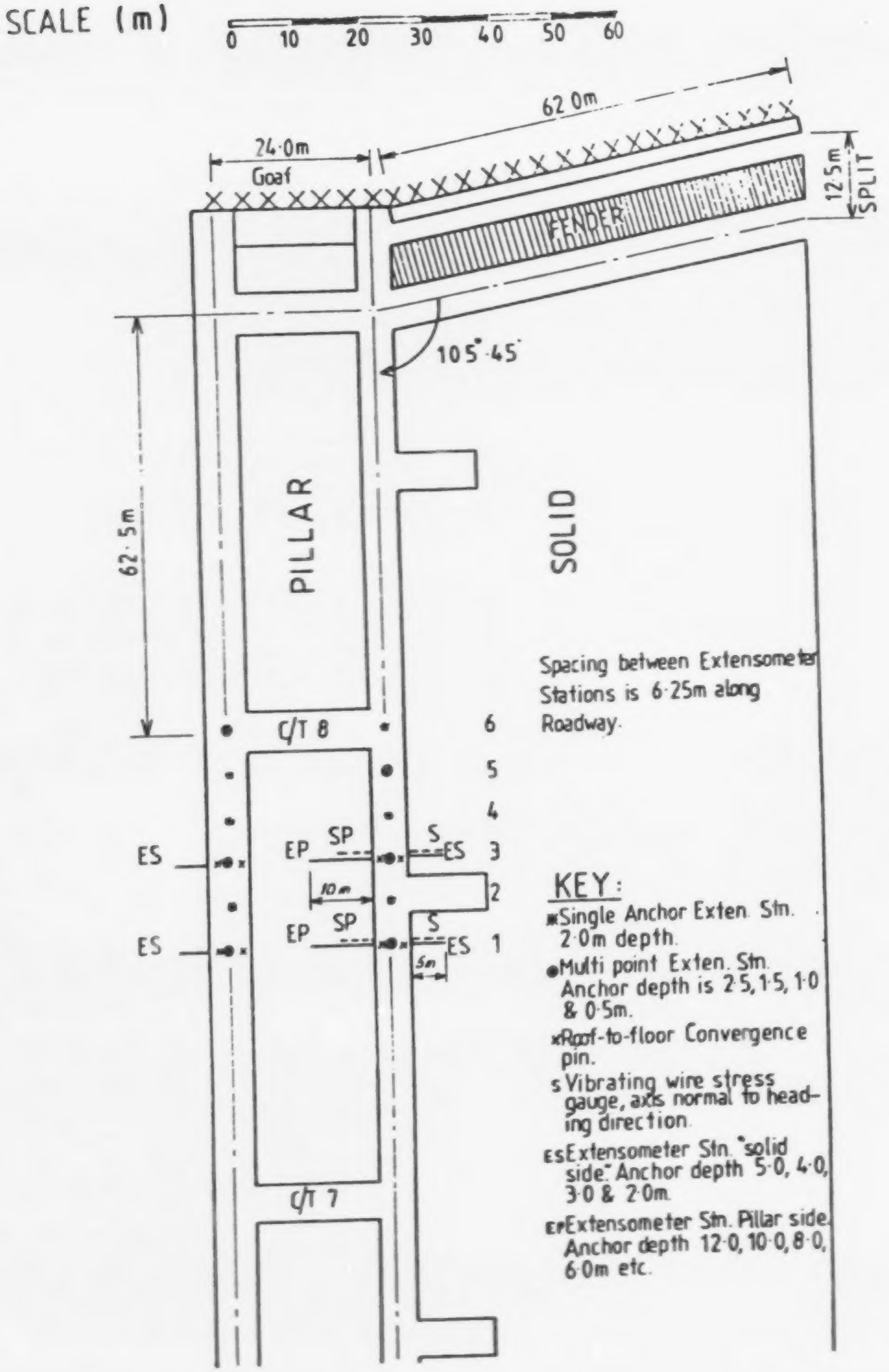

SCALE (m)
0 10 20 30 40 50 60
62.0m
24.0m
Goaf
12.5m
SPLIT
FENDER
105°45'
62.5m
PILLAR
SOLID
Spacing between Extensometer Stations is 6.25m along Roadway.
C/T 8
6
5
4
ES
EP
SP
S
ES 3
10m
2
ES
EP
SP
S
ES 1
5m
KEY:
×Single Anchor Exten. Stn. 2.0m depth.
●Multi point Exten. Stn. Anchor depth is 2.5, 1.5, 1.0 & 0.5m.
×Roof-to-floor Convergence pin.
s Vibrating wire stress gauge, axis normal to heading direction.
ES Extensometer Stn. "solid side." Anchor depth 5.0, 4.0, 3.0 & 2.0m.
EP Extensometer Stn. Pillar side. Anchor depth 12.0, 10.0, 8.0, 6.0m etc.
C/T 7

Figure 7. Coalcliff Colliery Monitoring Layout in 227 Panel.

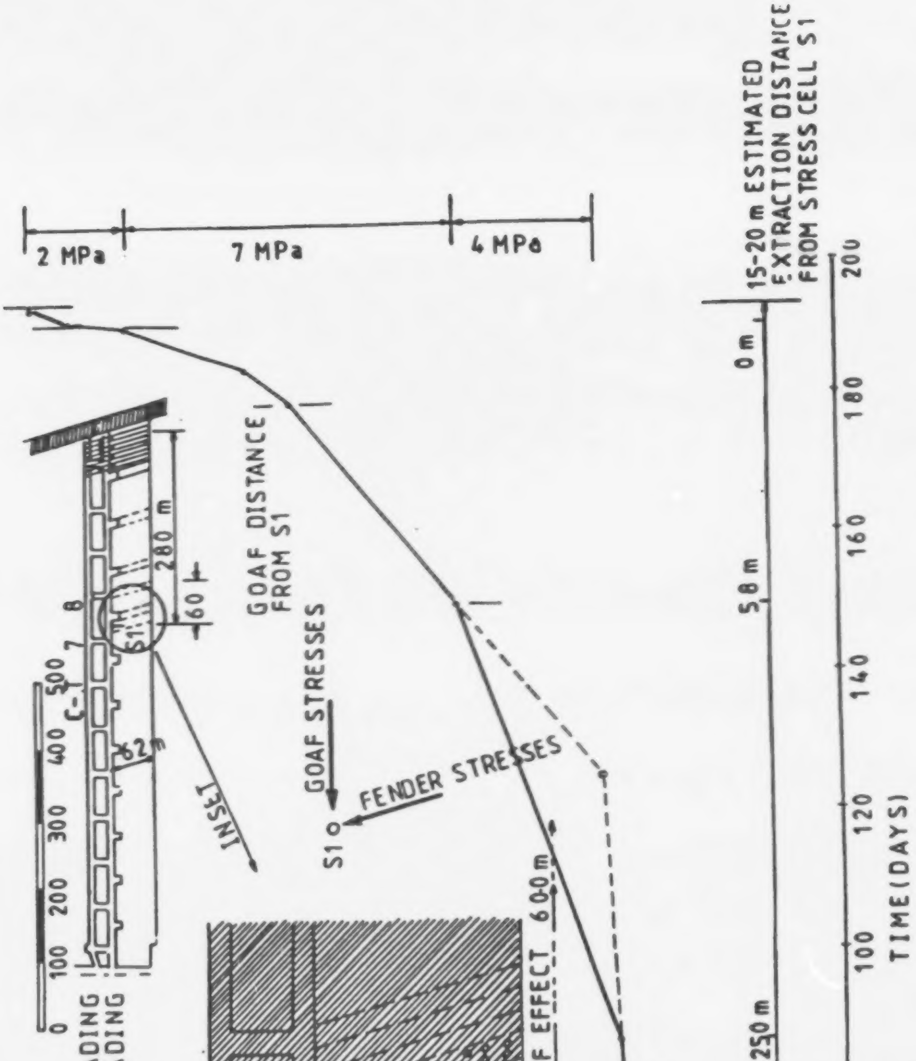


Figure 8. Stress Changes in the Solid Monitored by Stress Cell - S1.

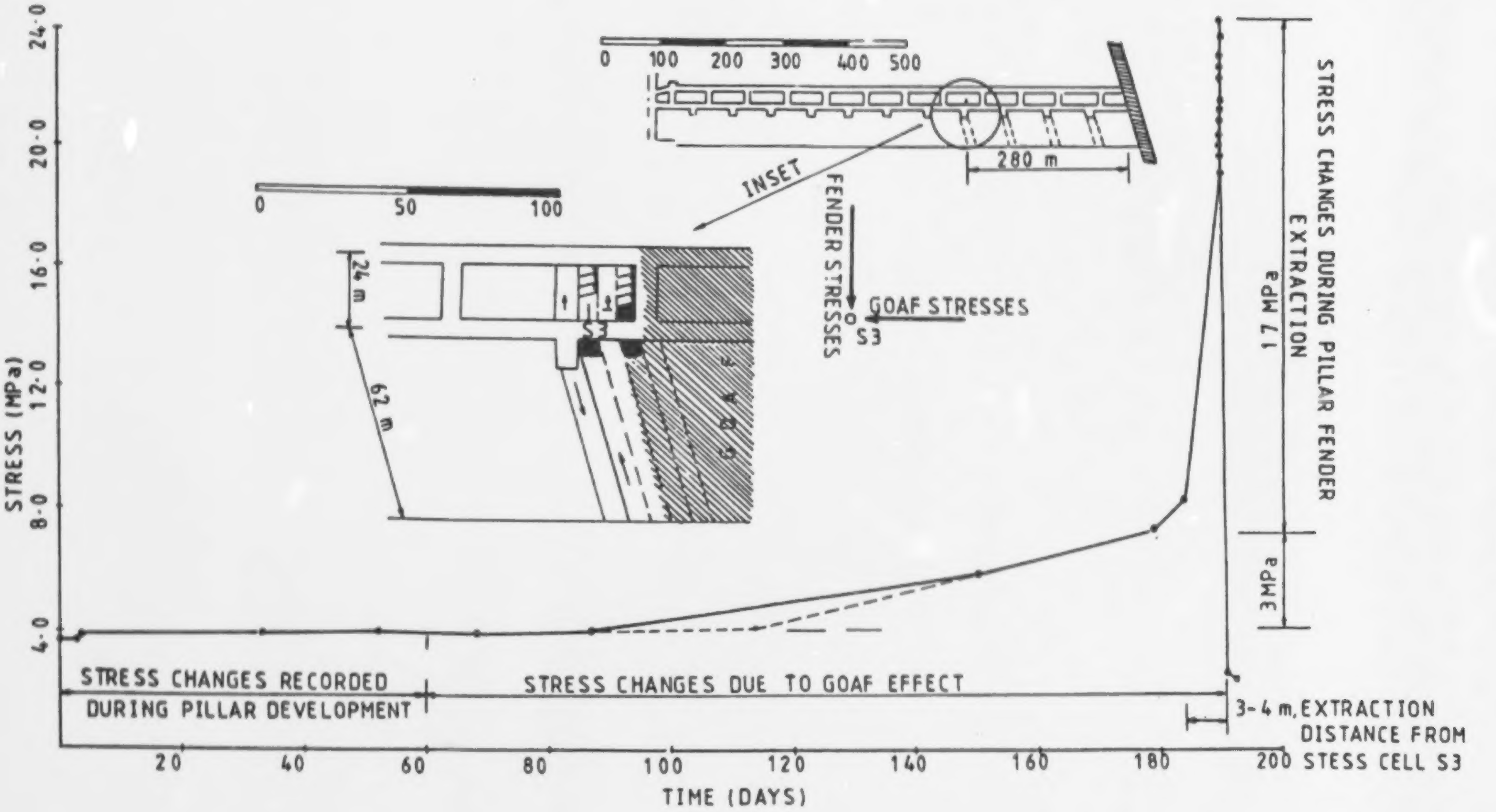


Figure 9. Stress Changes in the Pillar Monitored by Stress Cell - S3.

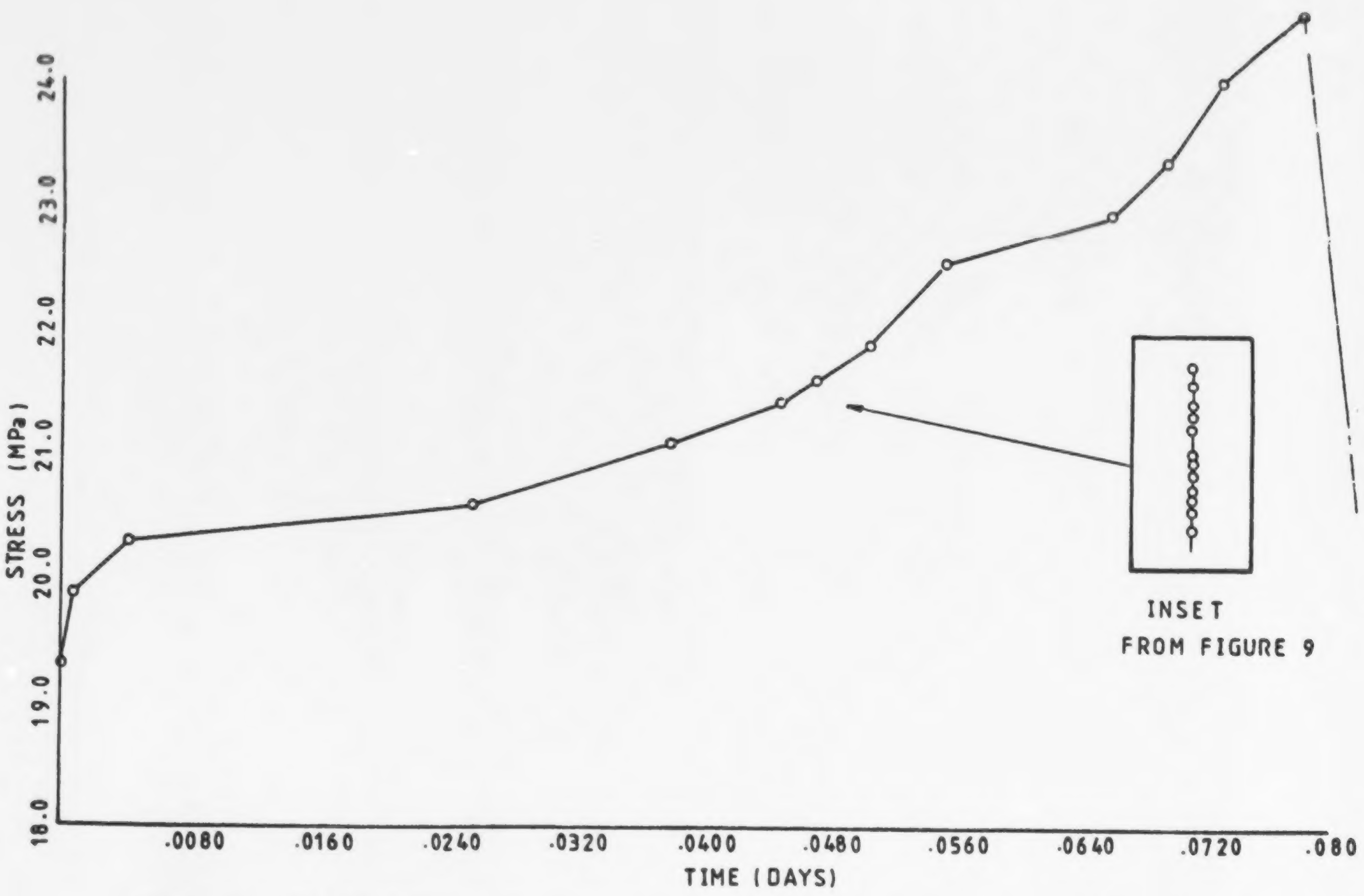


Figure 10. Detailed Stress Measurement taken during the Extraction of Adjacent Fender.

This caving mechanism produced the stress environment indicated in Figure 11. The hang up of the sandstone material transferred the peak abutment to a position approximately 15 m away from the goaf edge enabling the adjacent fender to be extracted under relatively destressed conditions. If the roof had been more friable the shear failure of this strata may have produced a peak stress on the fender or roadway making the extraction of the fender difficult.

The uniaxial compressive strength of the Bulli Coal Seam has been determined to be 22 MPa. From the stress measurements this value was slightly exceeded with a peak abutment of 24 MPa. However it must be highlighted that the coal was under confined conditions within the pillar core and therefore appreciably stronger and able to withstand the induced stress environment. This was certainly indicated by the competent nature of the fender coal.

Figures 8 and 9 indicate differences in the stress patterns. The stress as shown in Figure 9 rose gradually for a period of 180 days and then suddenly jumped 17 MPa from 7 MPa to 24 MPa, over a period of only 1 day. During this particular period the initial extraction of the pillar took place. Figure 10 shows the incremental stress changes which occurred during the above 1 day period. During the same day period continuous monitoring of the stress cell (S_3) showed a marked drop from the peak induced stress of 24 MPa to the initial setting stress of 4 MPa indicating the effectiveness of the fender extraction in the destressing of the adjacent area. Whilst the adjacent area was destressed, another stress cell (S_4), located within the same pillar, 20 m outbye, recorded an increase in stress indicating that the stress had been relocated. If one could draw a sectional profile of the stress movement along the pillar throughout the extraction cycle it would appear in a wavelike form across the pillar. From the results it can be seen that the objectives of the Wongawilli system have been technically and practically proven correct.

5.3 PILLAR STRAIN PROFILE

A number of extensometers were installed in the ribs of the coal pillar and the solid extraction block, the aim being to determine the strain profile during coal extraction.

Figures 12, 13 and 14 show the strain measured at selected borehole horizons within the pillar and the solid coal block. The strain measured has also been related to the time and the goaf extraction distance. From these graphs it can be seen that higher magnitudes of strain were measured close to the pillar and the solid coal block ribs, such magnitudes dropping very rapidly into the pillar and solid coal block. 70 days after the start of the panel extraction, the goaf was approximately 140 m from the extensometer stations. During this time the strain increased to around 0.3% on both sides of the belt and the return headings. When the goaf was 30 m from the extensometers the strain reached a value of approximately 1% on both sides of the belt heading and 0.3% on both sides of the return heading side. Finally, when the goaf was about 10 m from the extensometers, the strain was approximately 1.55% on both sides of the belt heading and 0.6% on both sides of the return heading.

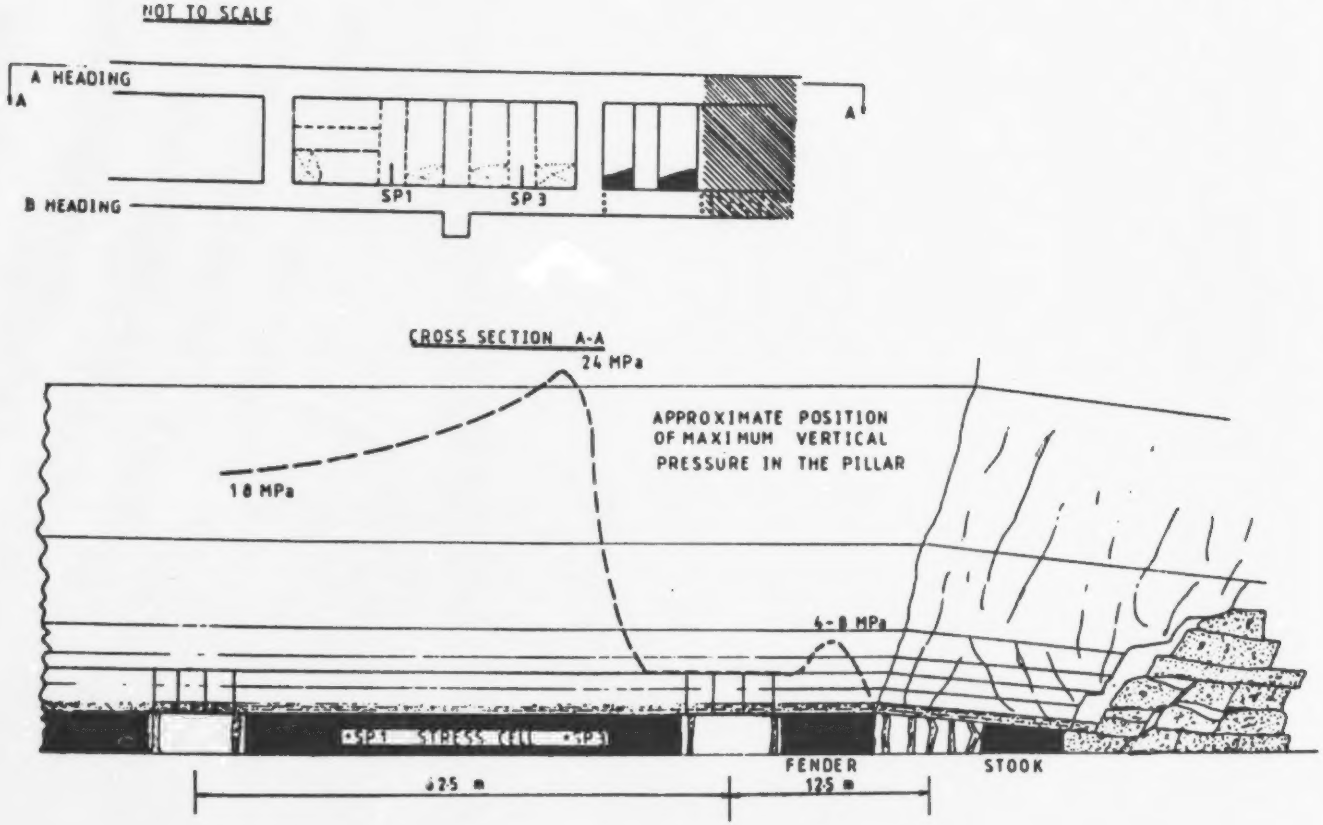
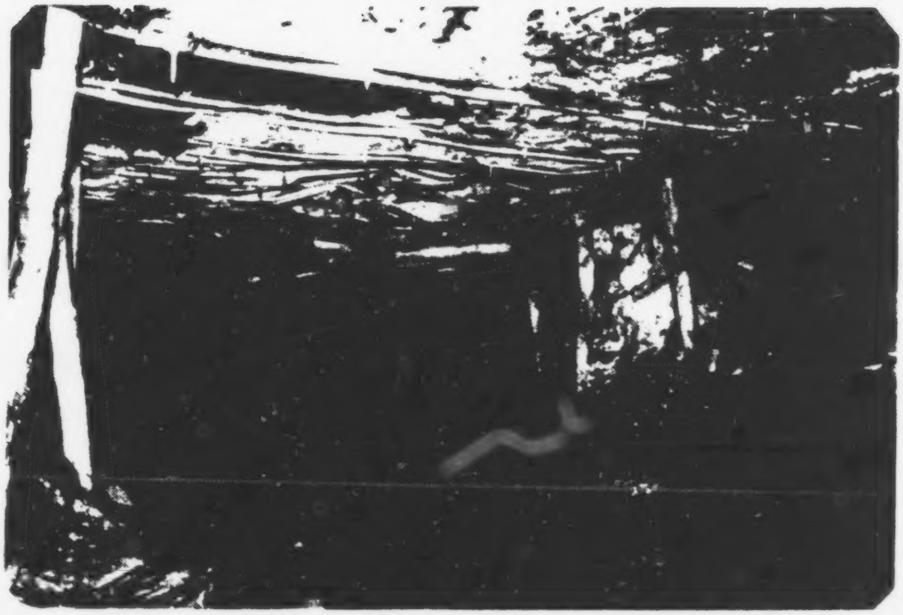
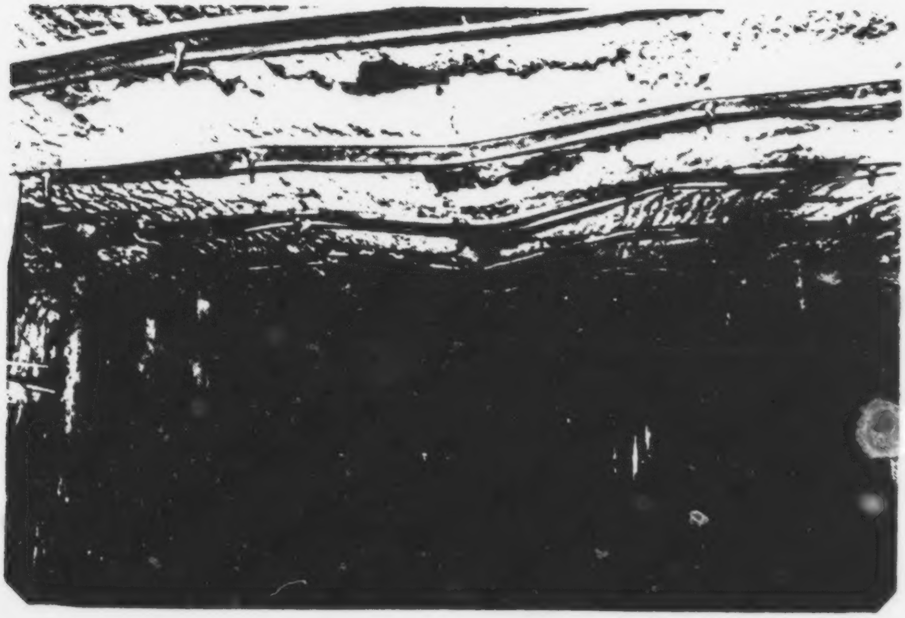

NOT TO SCALE
A HEADING
A
A
B HEADING
SP1
SP3
CROSS SECTION A-A
24 MPa
18 MPa
APPROXIMATE POSITION OF MAXIMUM VERTICAL PRESSURE IN THE PILLAR
4-8 MPa
SP1 STRESS CELL SP3
FENDER
STOOK
62.5 m
12.5 m

Figure 11. Goaf Effect on Stress Distribution Across the Pillar.



(a) Goaf Conditions as seen from A Heading Return Roadway.



(b) Roof Deformation in Belt Road 50 m from the Face.
PLATE 1.

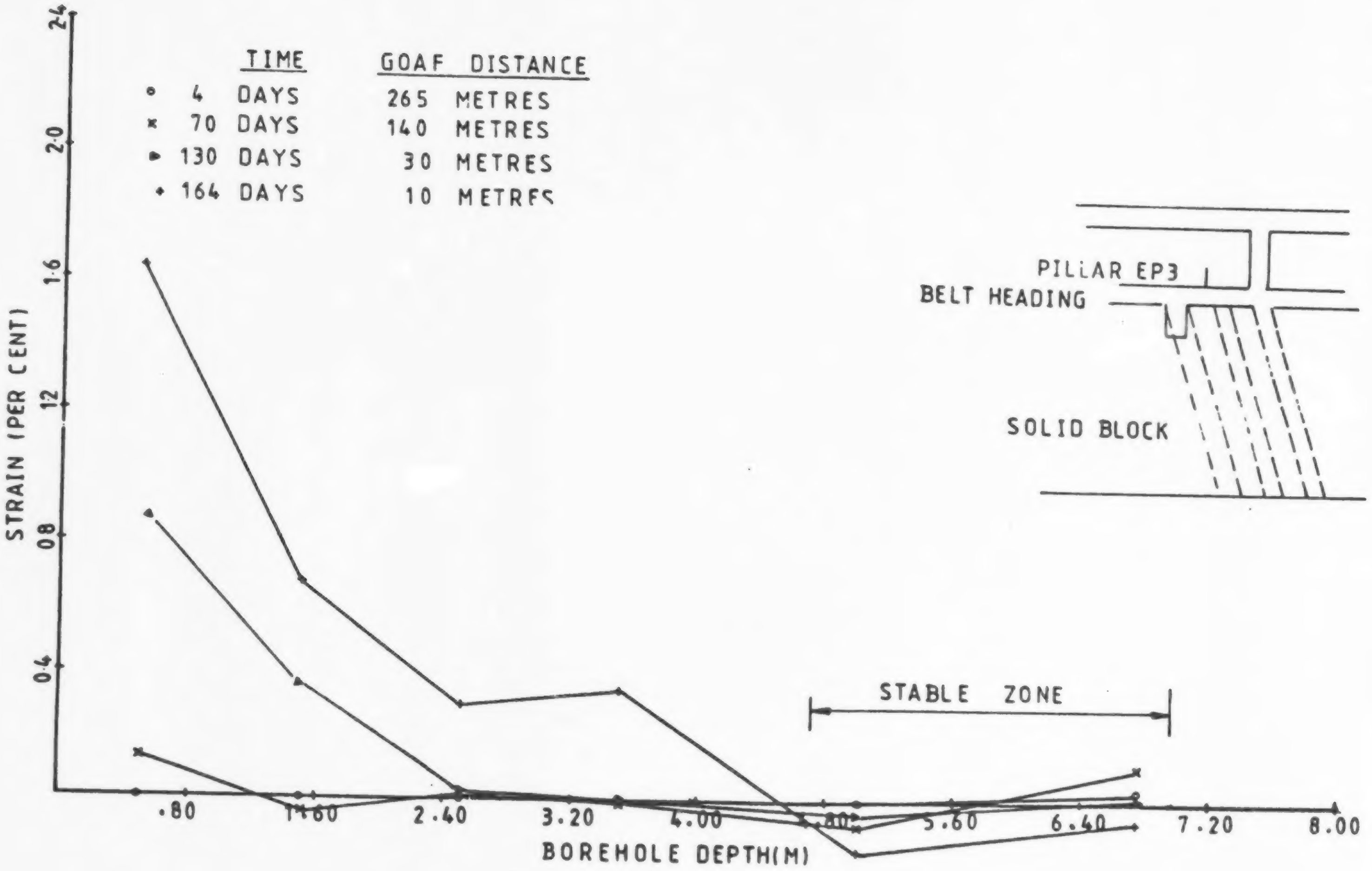


Figure 12. Strain Vs Anchor Depth on the Belt Heading Side of the Pillar - Station EP3.

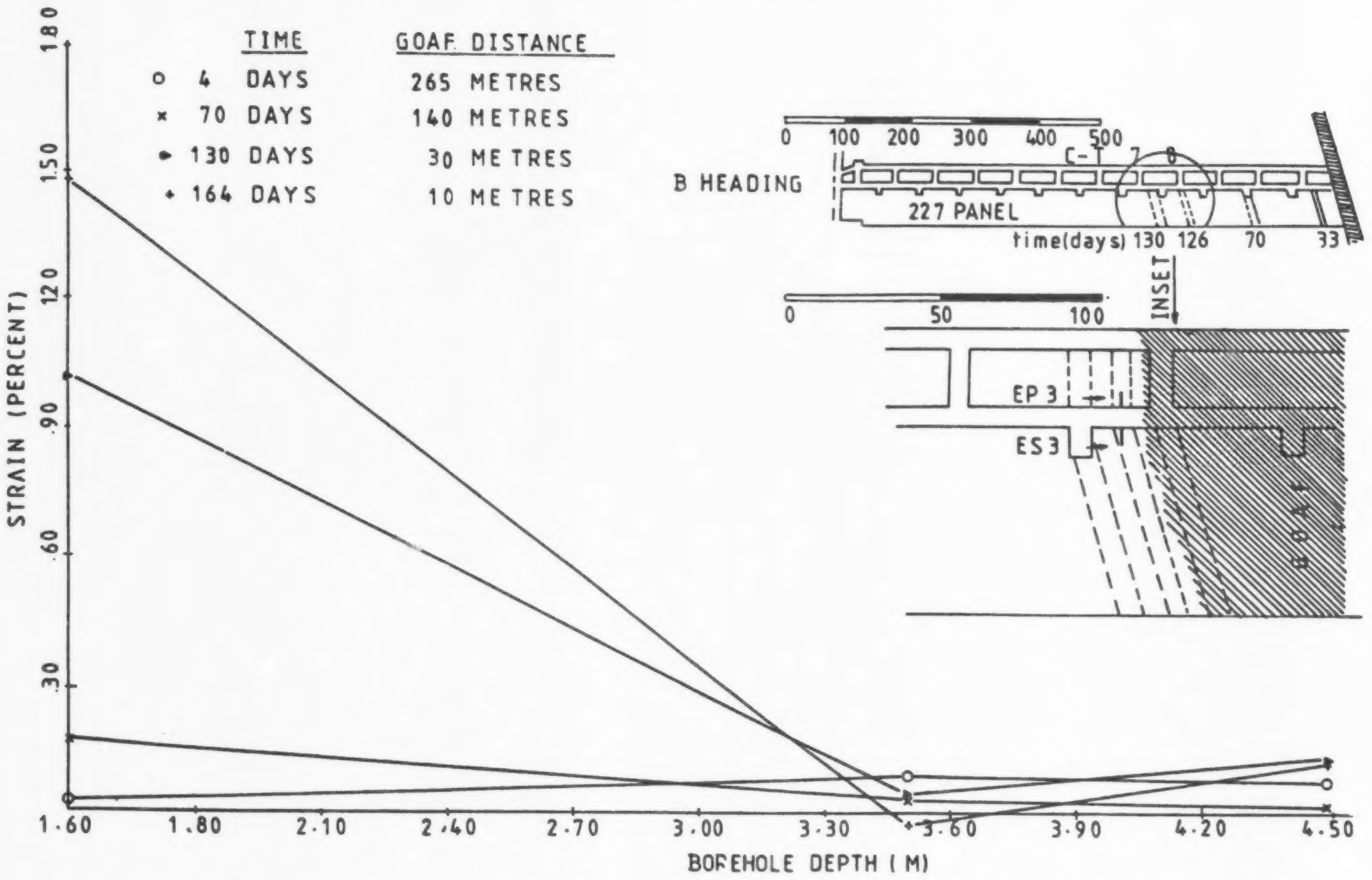


Figure 13. Strain Vs Anchor Depth on the Belt Heading Side of the Solid - Station ES3.

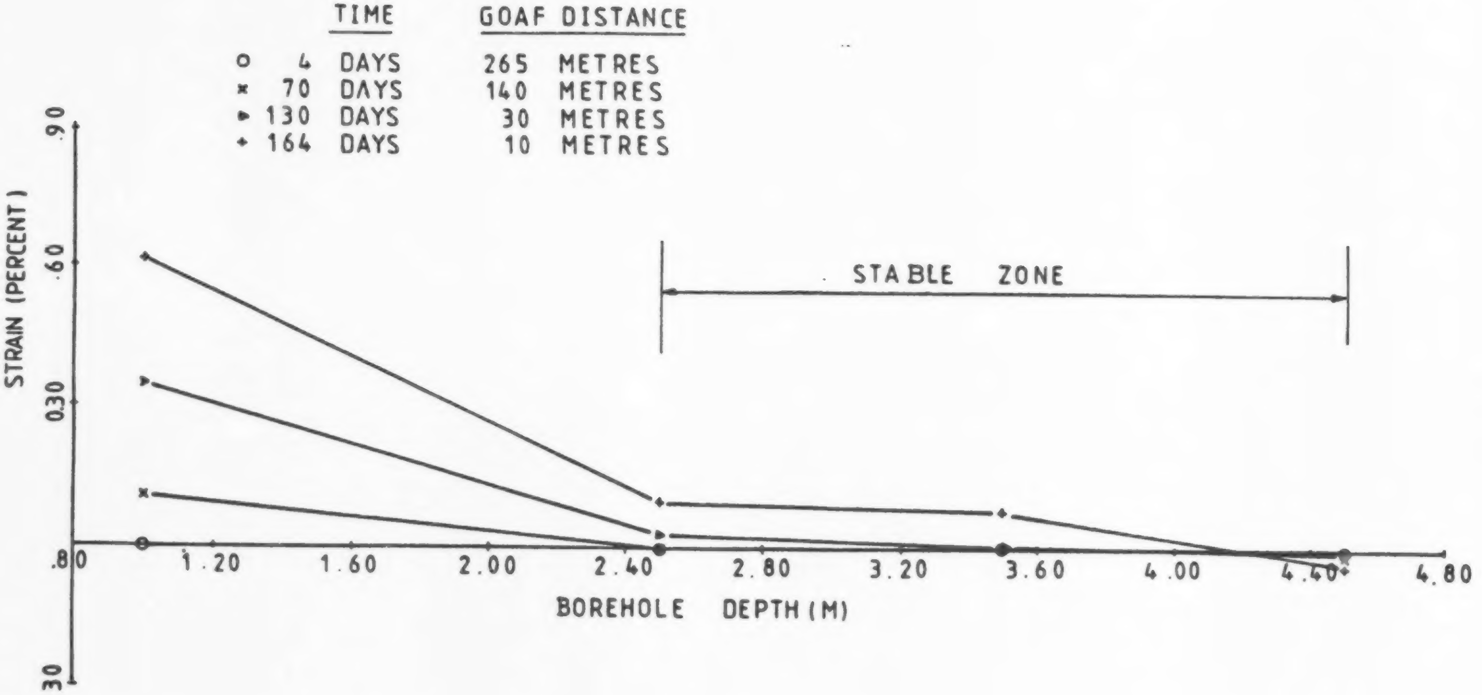


Figure 14. Strain Vs Anchor Depth on the Return Heading Side of the Solid - Station ES3.

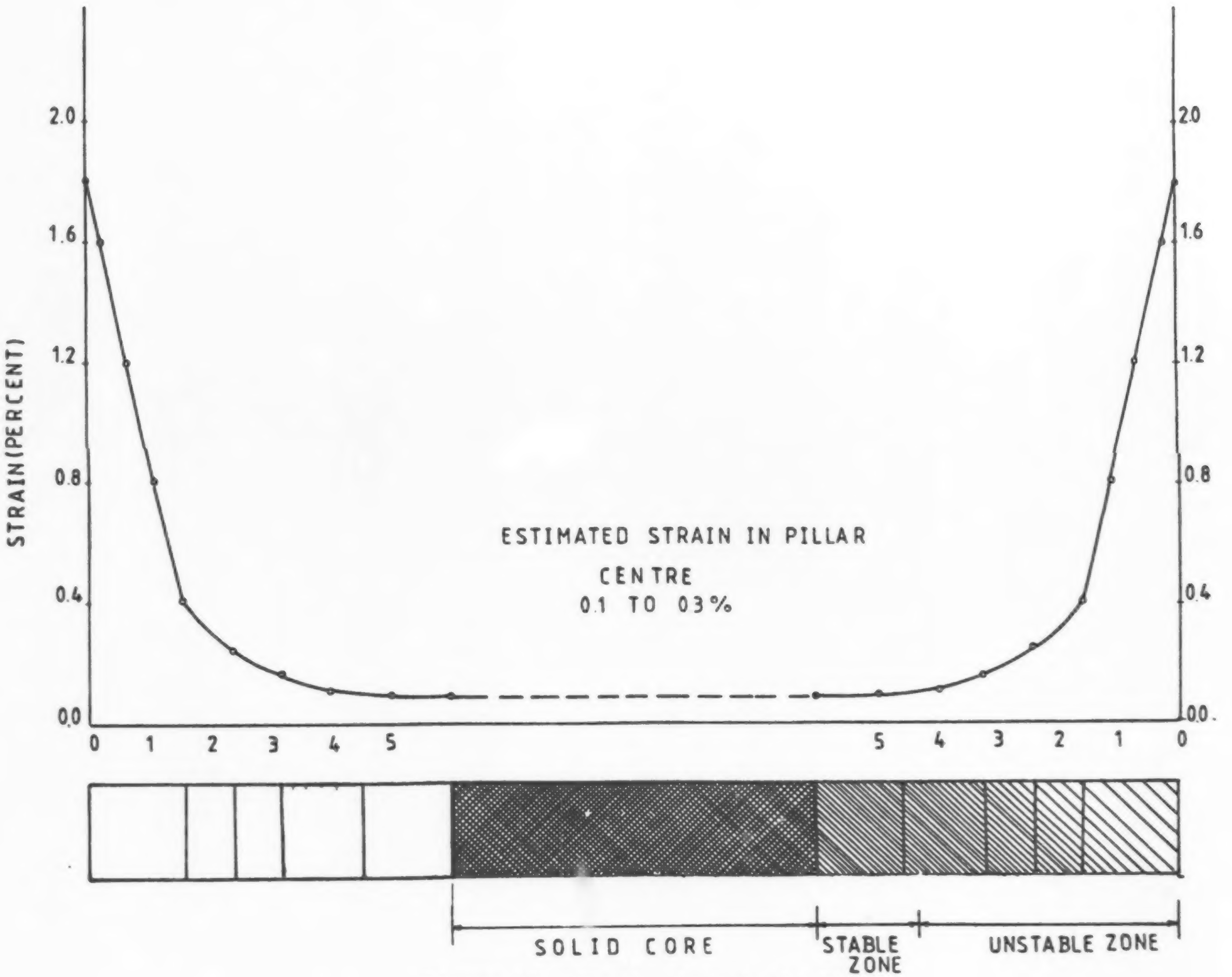


Figure 15. Strain through the Pillar.

From these figures it can be seen that the strain was much less, adjacent to the return heading where a larger stable zone existed. Taking the mean of the strain values shown on Figures 12 and 13, a strain through the stabilising pillar can be constructed. Figure 15 shows such strain construction for a period of 135 days after the start of the extraction in 227 Panel. The mean strain between 3 m and 5 m on both sides of the pillar was less than 2% as was the strain through the core. These graphs also indicate that, under development conditions, pillars with a solid core of approximately 9 m would offer long term stability.

5.4 PILLAR DEFORMATION IN RELATION TO EXTRACTION SEQUENCE

Figures 16, 17, 18 and 19 plot deformation and strain, measured between each anchor position and the mouth station, with respect to time and goaf distance. The difference in deformation between each anchor curve represents the deformation occurring within the zone or bay between anchors at any particular time. The increasing slope indicates increasing instability. The maximum measured horizontal deformation in the pillar between each of the deepest anchors and the mouth station was 35 mm, as shown in Figure 17. This maximum horizontal deformation has a corresponding maximum strain of 2%, as shown in Figure 16.

The highest deformation at the solid side of the belt heading was higher than the deformation occurring within the pillar. This is shown in Figures 18 and 19. The highest deformation on the solid side of the return heading was, however, lower than that detailed above. This is shown in Figures 20 and 21.

Figures 16, 18 and 21 indicate that the maximum strain levels were between anchors 1 and 2, i.e. between 1 m and 2 m into the pillar and the solid. This may have been due to the fact that the outer zones of the solid and pillar were relaxing. The bay from 2 m to 4 m had the next lowest strain, however the lowest strain was measured between 4 m and 6 m depth.

Another significant characteristic of these figures is that they enable the evaluation of the extent of influence of the abutment zone. For example, the forward abutment on the solid side of the return heading was 170 m long, while the immediate abutment was 10-20 m in extent (see Figure 20). On the belt heading side the extent of the forward abutment was 130 m while the immediate abutment was between 20-30 m (see Figure 17).

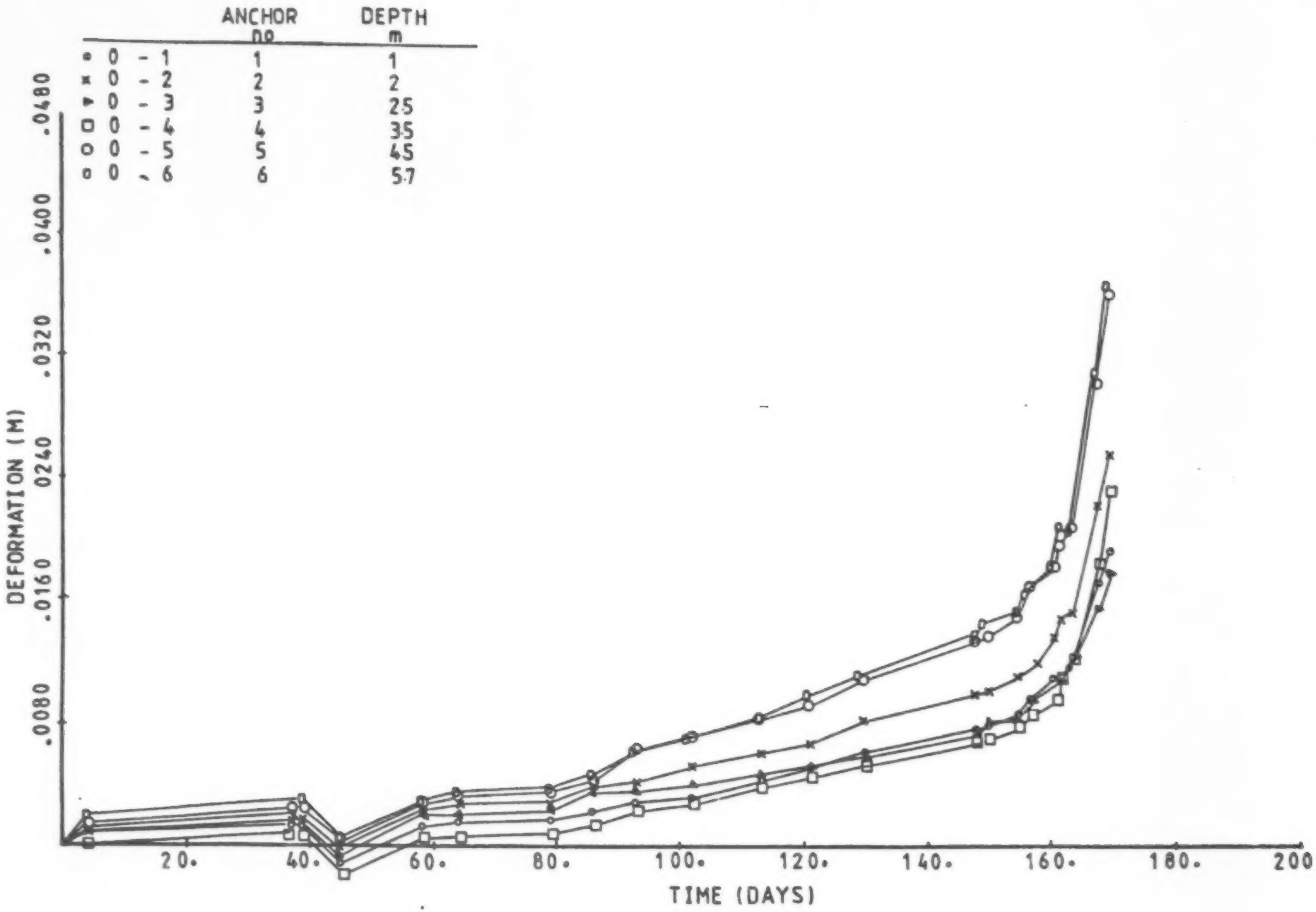


Figure 16. Pillar Deformation on Belt Heading Side - Station EP1.

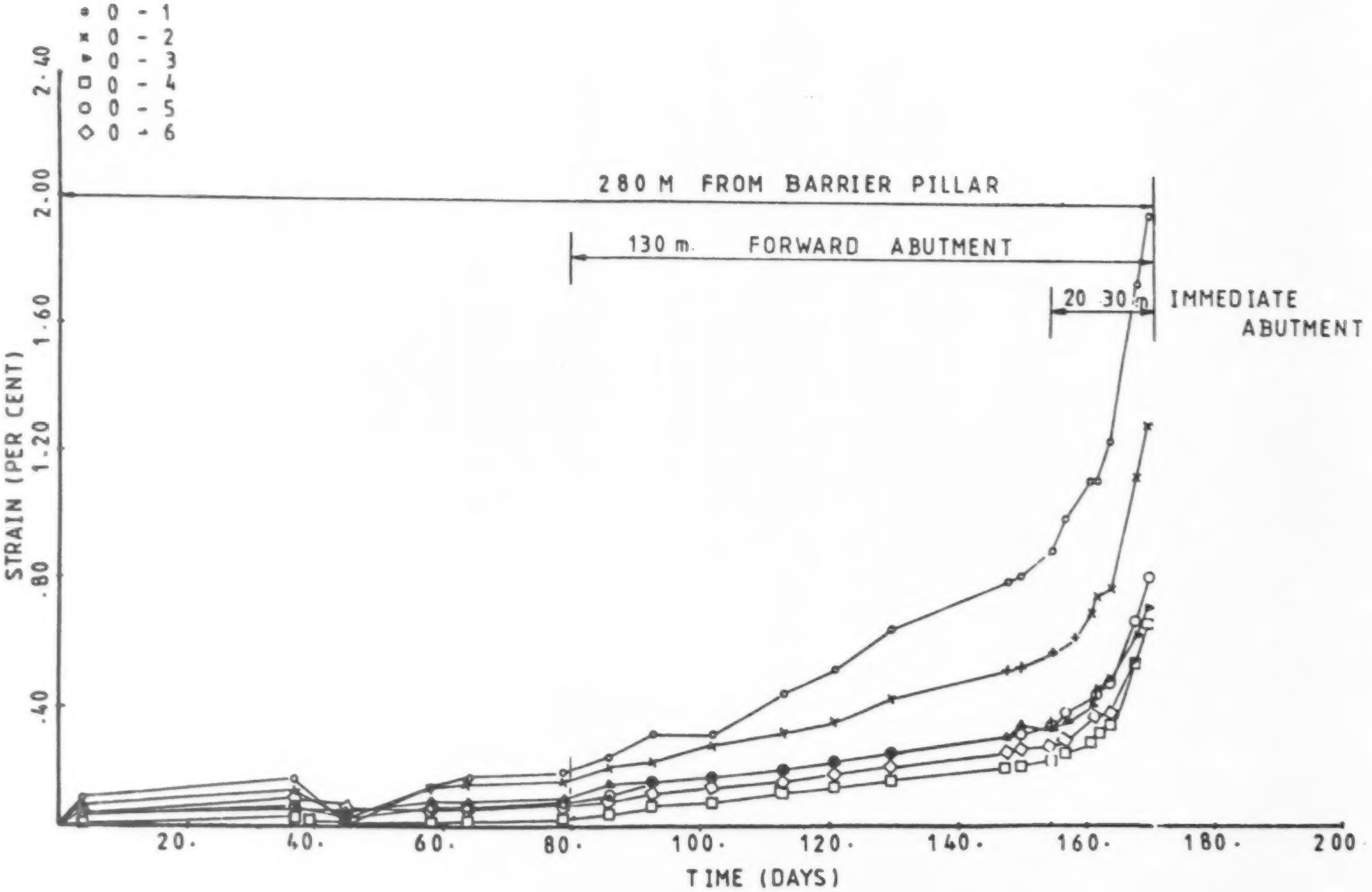


Figure 17. Pillar Strain - Station EP1.

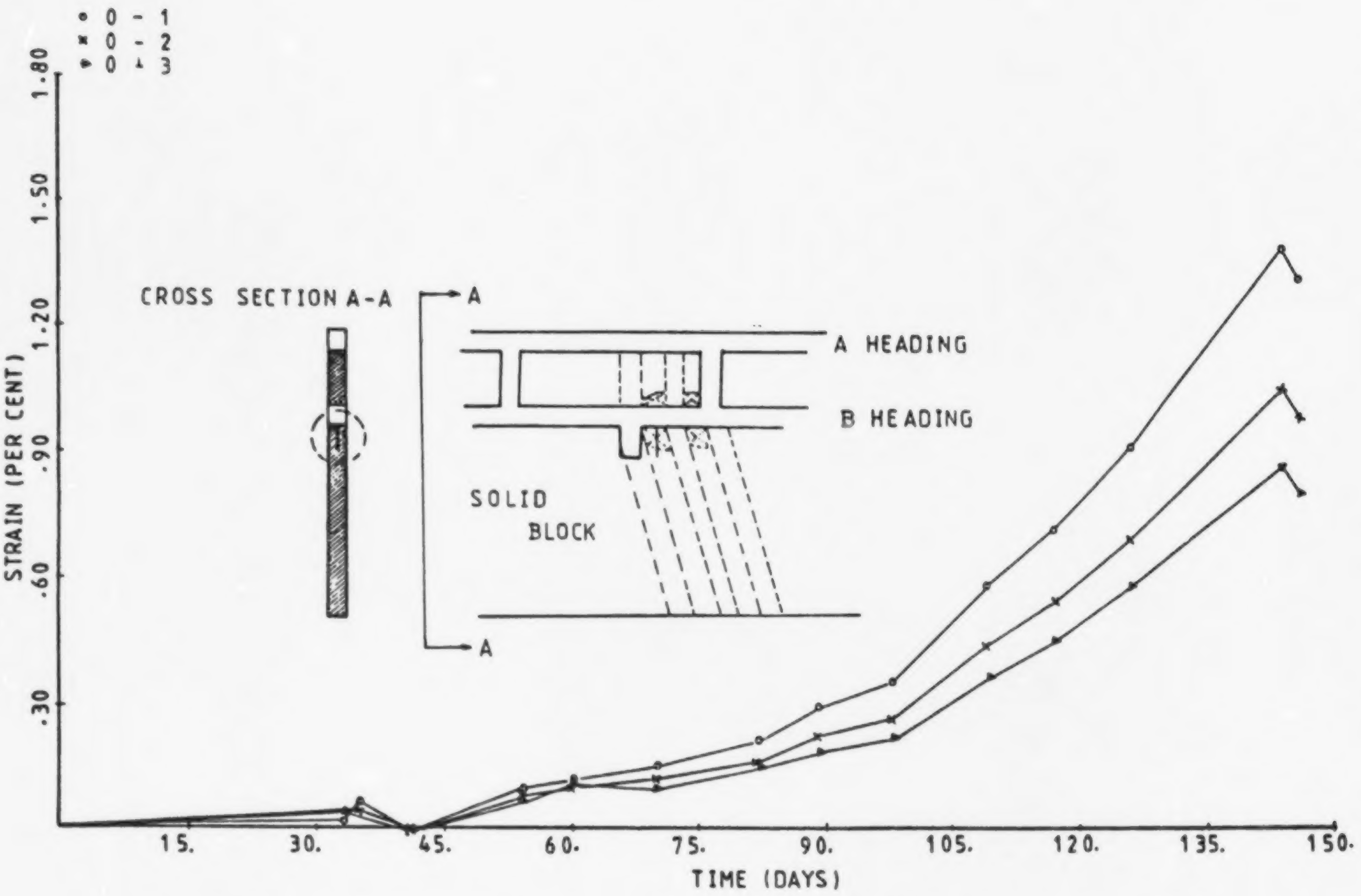


Figure 18. Strain through the Solid on the Belt Heading Side - Station ES 3.

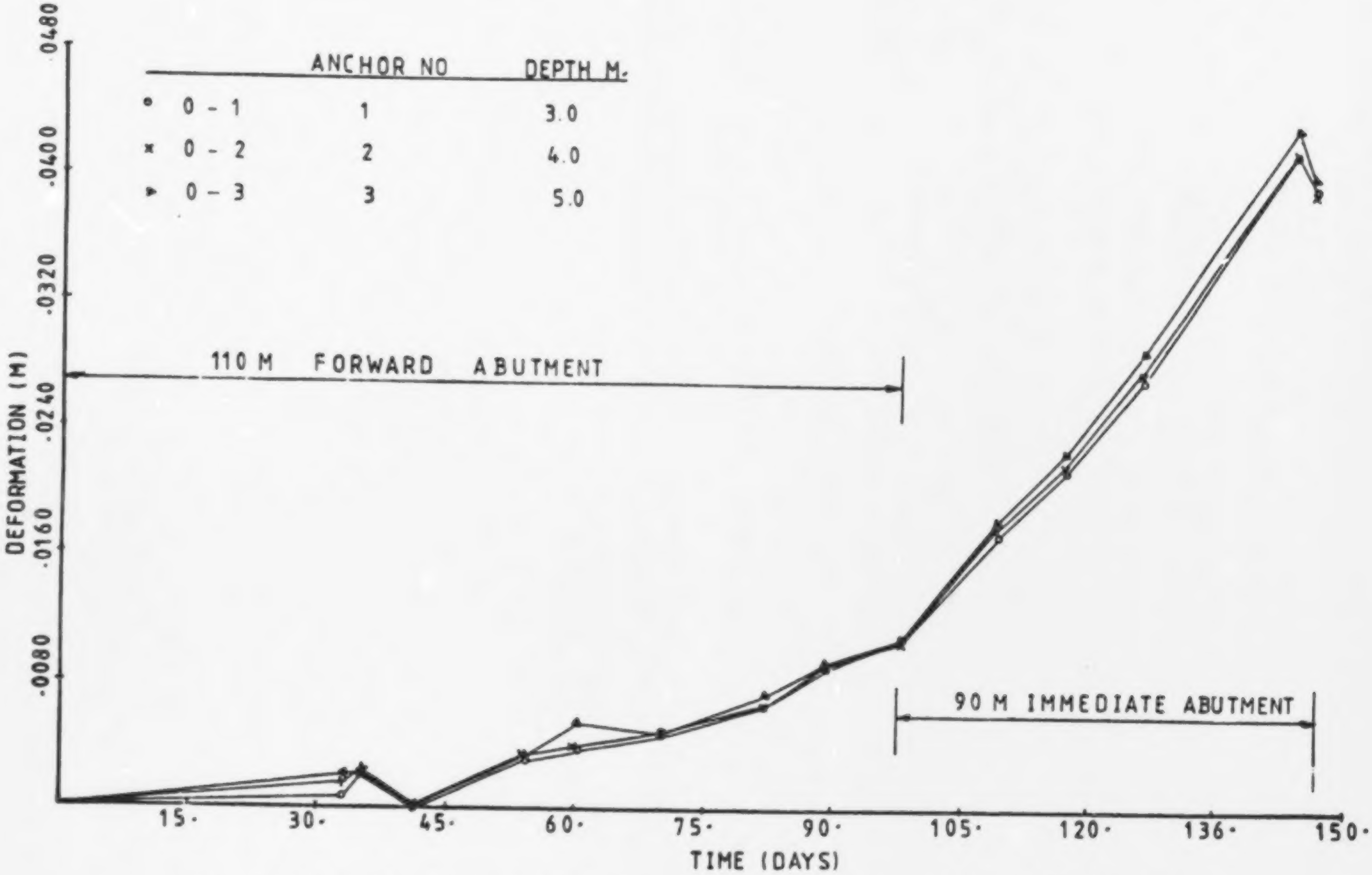


Figure 19. Solid Block Deformation on the Belt Heading Side - Station ES3.

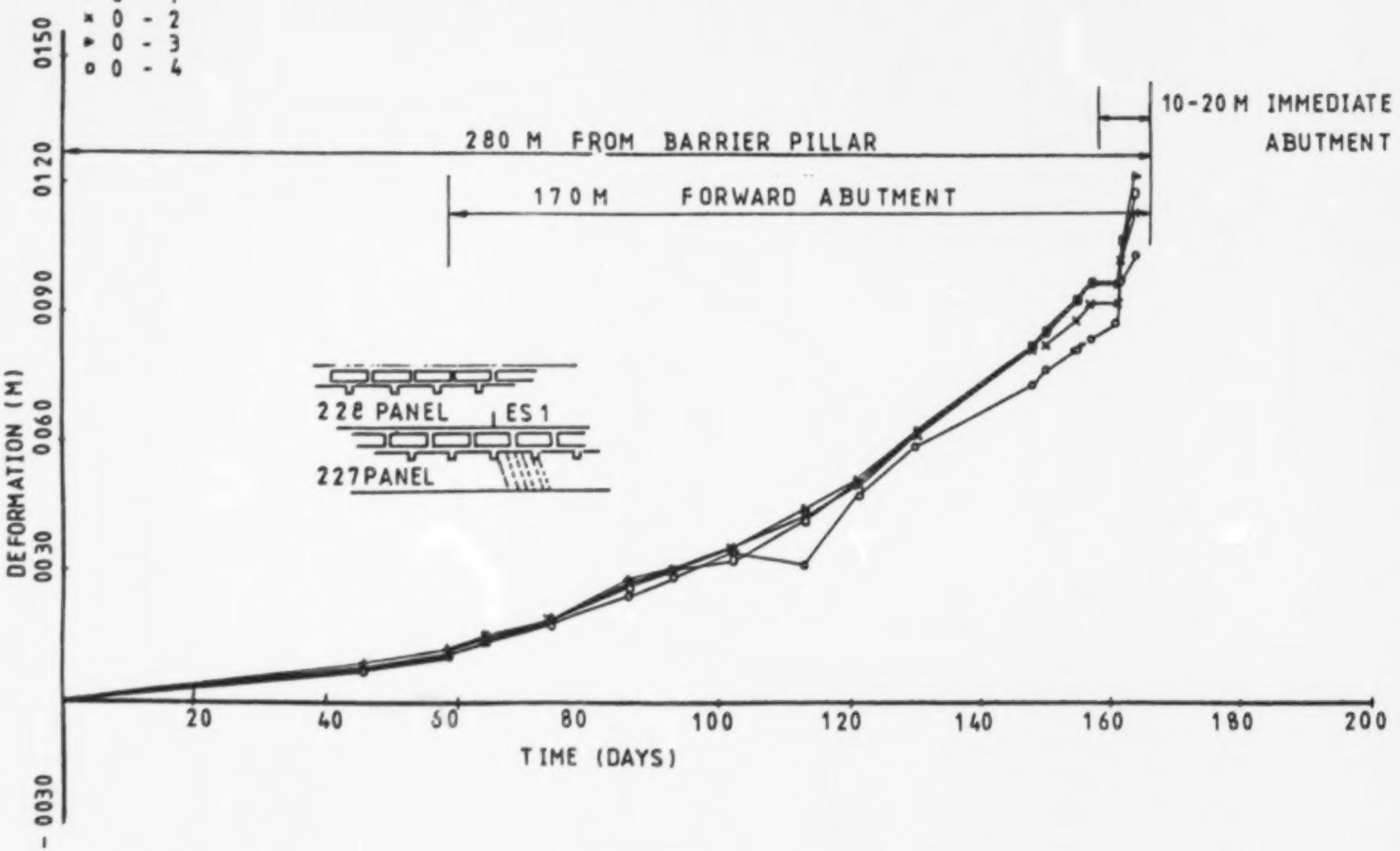


Figure 20. Solid Block Deformation on the Return Headings Side - Station ES1.

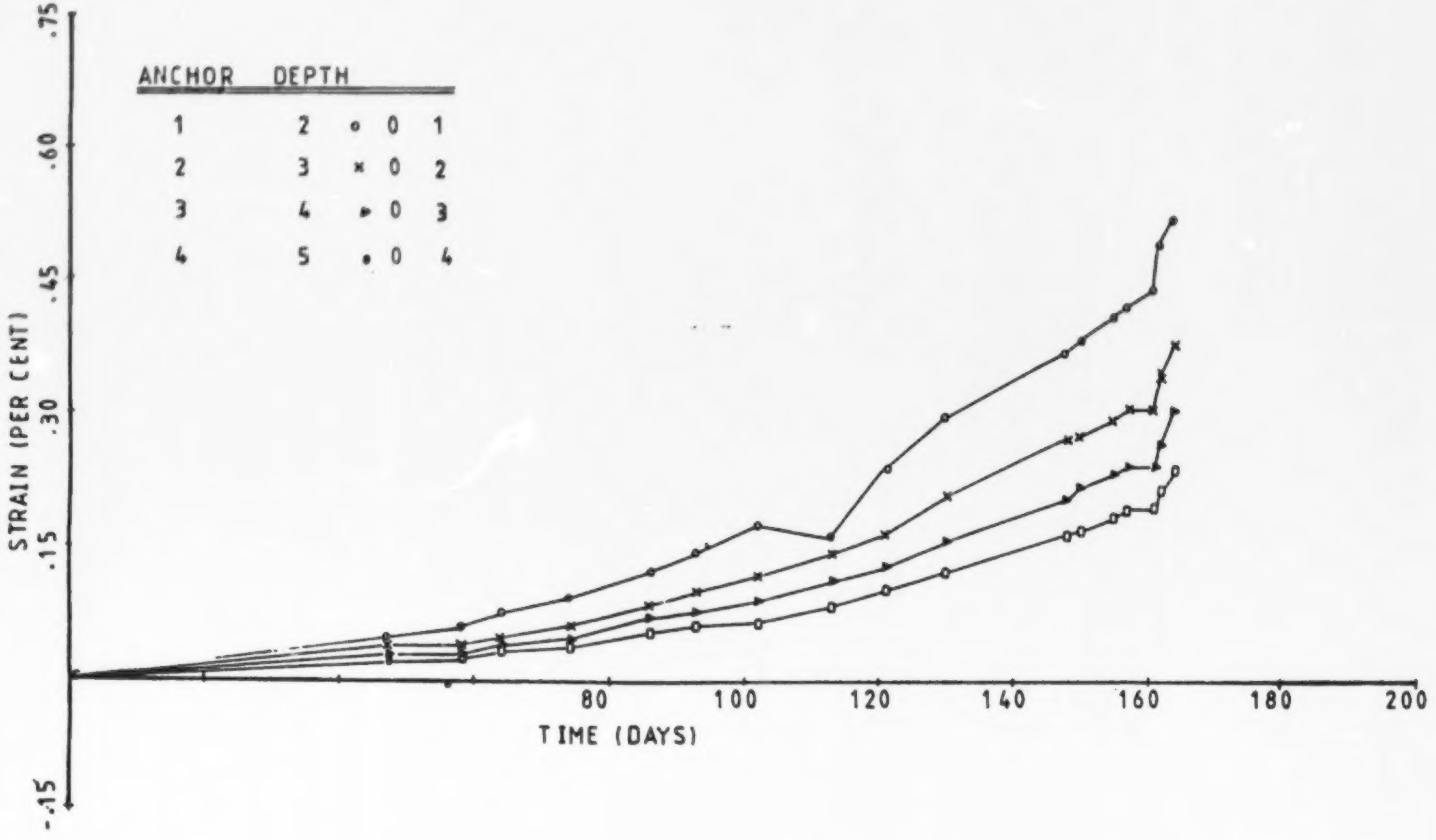


Figure 21. Strain trhough the Solid Block on the Return Heading Side - Station ES1.

5.5 ROADWAY STRAIN AND DEFORMATION MEASUREMENTS

The immediate roof strata over the investigation site comprised three layers of mudstone and sandstone with differing thicknesses as is shown in Figure 22. These layers were under increased stress during the extraction cycle which caused them to deform. The positions of the roof extensometers are also shown in Figure 22.

Return Heading

Figures 23 and 24 illustrate strain and deformation measurements obtained from extensometer station S_1, where three extensometers were installed across the return heading from the left hand side to the right hand side looking inbye. The centre extensometer was 2.04 m in length, four shells being installed at the following horizons: 0.5, 1.0, 1.4 and 2.04 m. The extensometer on the left was 2.0 m in length and comprised one shell. The right hand side extensometer was 1.2 m in length and comprised one shell also.

The graphs show that the roof was tilting towards the pillar, which in fact was confirmed by strain and deformation readings obtained from each extensometer. Relative to the above statement the strain and deformation measured with the left hand side extensometer was near zero in value. The respective values measured with the middle extensometer showed an increase of 0.30% maximum strain and 2 mm deformation. Finally these values as measured with the right hand side extensometer showed that the strain in the roof had reached a maximum of 1.6% and deformation was 14 mm.

Belt and Track Heading

Figures 25 and 26 represent results obtained from station E_3, installed in the belt and track heading. This station consisted of three extensometers installed across the heading from left to right looking inbye.

Roof behaviour over this section of the belt and track heading was similar to that of the return heading. In this regard there was a slight tilting of roof towards the pillar on the left hand side of the roadway looking inbye. Figure 25 shows that the deformation gradually increased on the left hand side of the roof over a period of 120 days finally reaching a maximum of 28 mm, and a corresponding 18% strain. The strain and deformation obtained from the extensometer in the centre were less than those obtained from the left hand side. The extensometer on the right hand side showed only slight signs of roof deformation or movement over the same period of time. However, when the goaf was between 5 m-10 m from the station a sudden jump in deformation was recorded, the magnitude of this jump being from 4 mm to 40 mm, the corresponding strain being from 0.2% to 2.8%. This acceleration in the deformation typifies roof material which is unstable and will eventually fail.

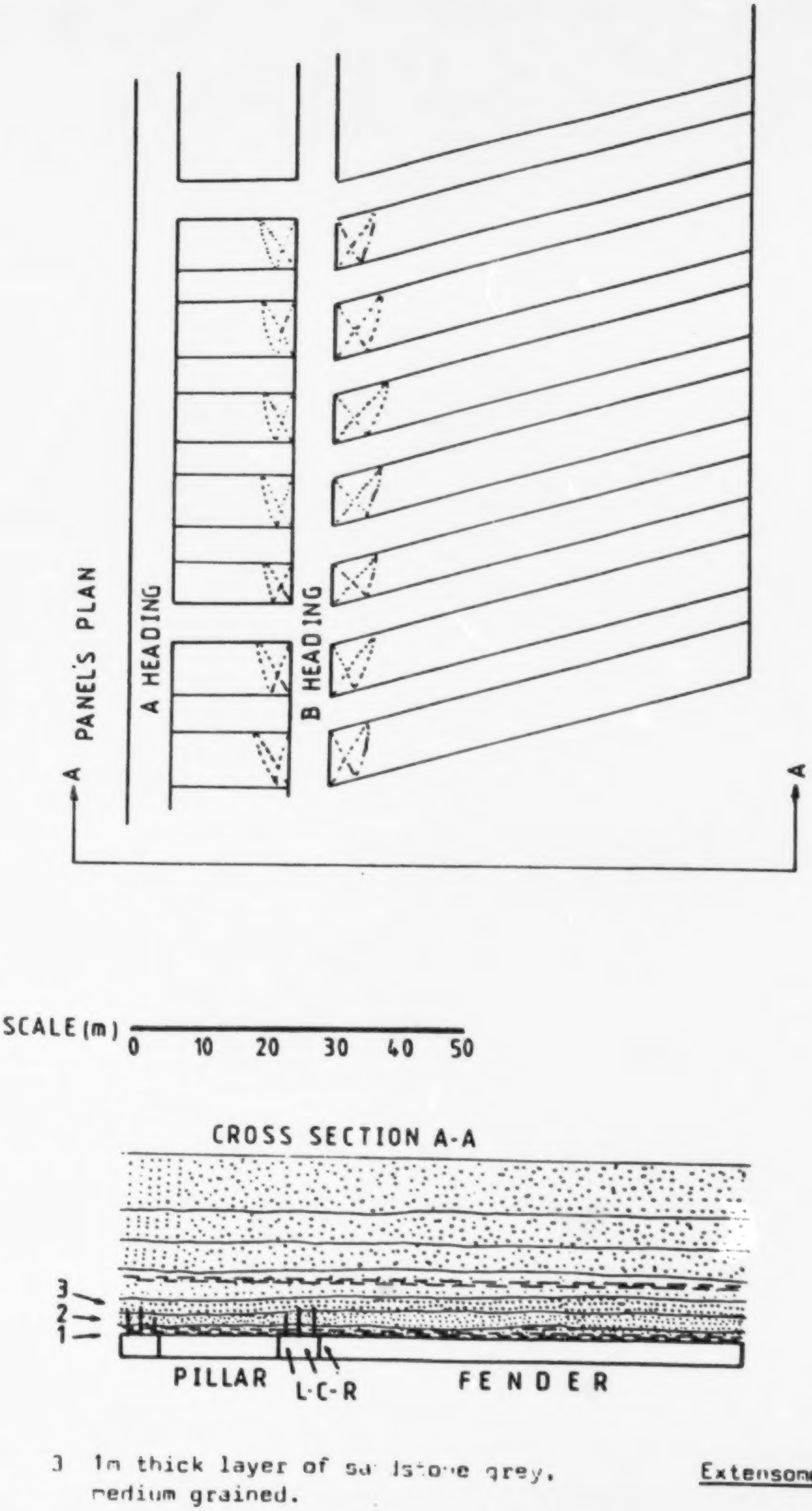

PANEL'S PLAN
A HEADING
B HEADING
A
A
SCALE(m) 0 10 20 30 40 50
CROSS SECTION A-A
3
2
1
PILLAR
L-C-R
FENDER

Figure 22. Roof Strata Formation at the Investigation Site.

3 1m thick layer of sandstone grey, medium grained.

2 1m thick layer of sandstone grey, fine grained.

1 0.4-1.8m thick layer of mudstone roof.

Extensometers

L = Left

C = Centre

R = Right

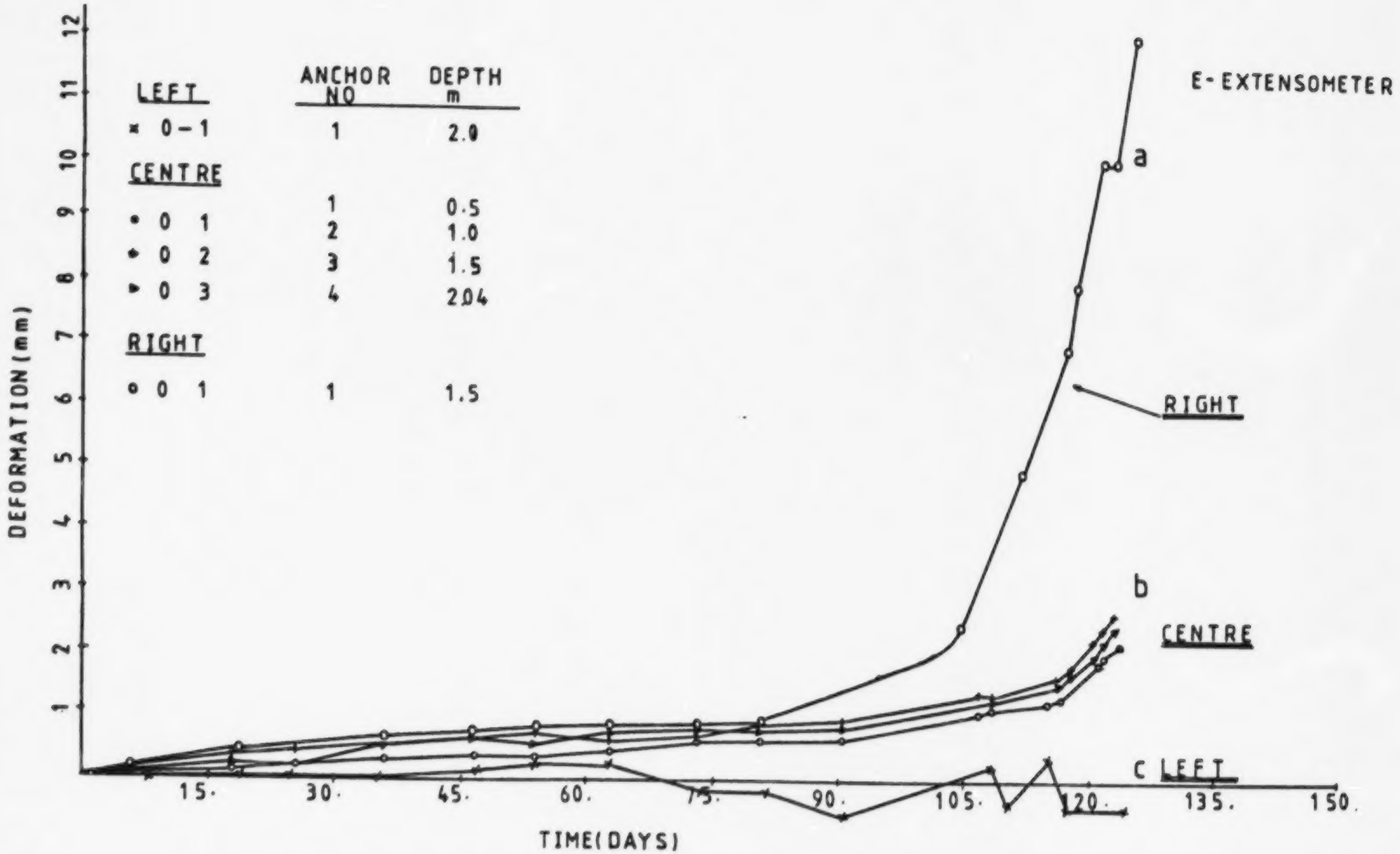


Figure 23. Roof Deformation at Station El in the Return Heading.

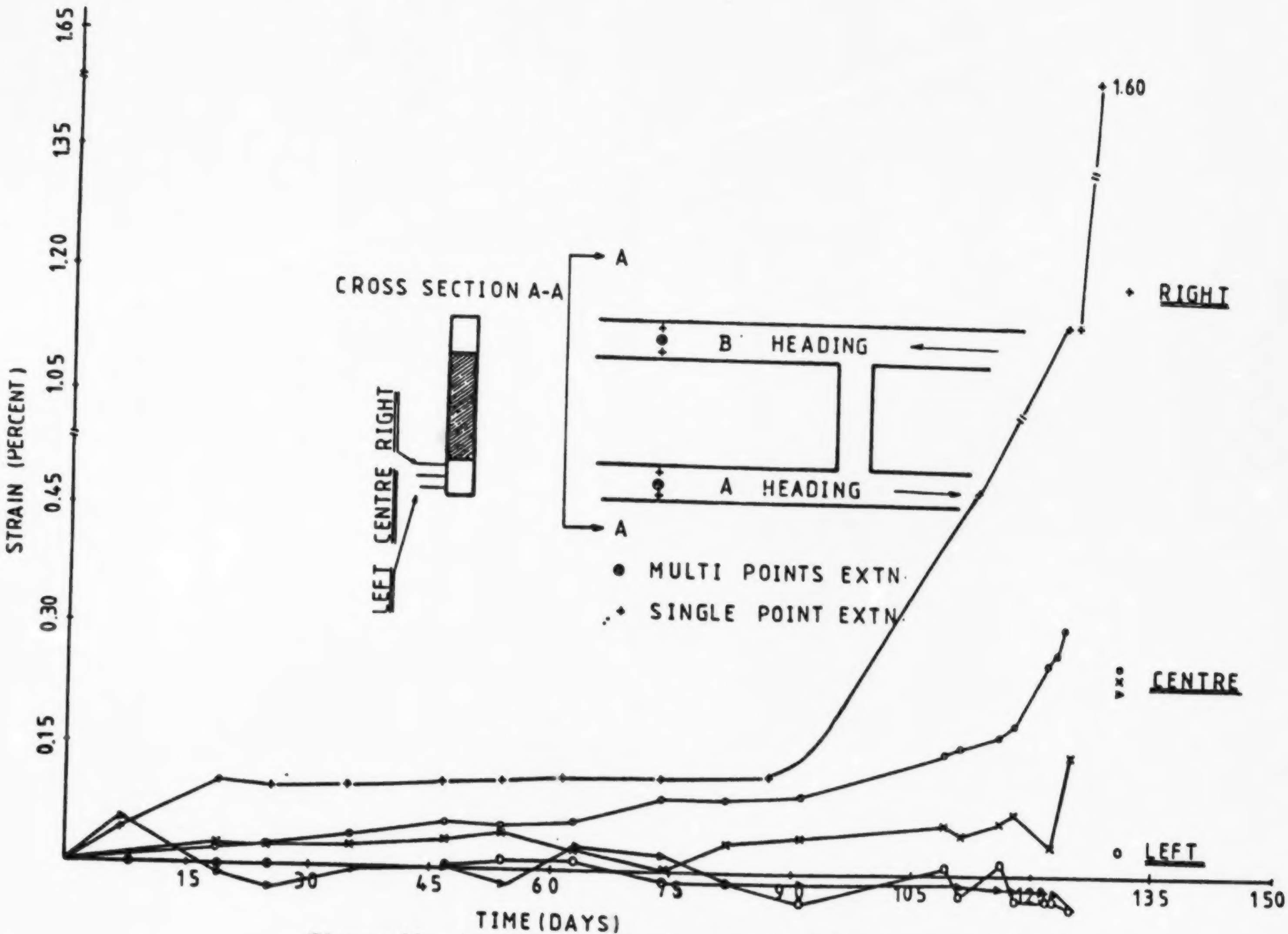


Figure 24. Roof Strain at Station El in the Return Heading.

From Figure 26 it can be seen that the centre extensometer indicated that the maximum strain was occurring between 0.5 m and 1 m into the roof. This was due to a single bed separation plane between the immediate mudstone roof layer and the overlying sandstone.

Figures 25 and 26 highlight the degree of stability with respect to time for each horizon within the strata. This plot is a routine monitoring aid and can be used to identify potential instability before a roof fall, and the height at which the instability is developing.

Summary of Roof Tilting

The roof tilting which was evident at the investigation site suggested that uneven stress distribution existed across the belt and return headings. The stresses were concentrated over an area of the heading which could result in rib spalling and roof guttering as shown in Plate 2.

From previous discussions concerning roof deformation, some sections of the roof in A Heading (return) had tilted toward the pillar, and also in B Heading a part of the roof had tilted toward the pillar; however the roof closer to the solid coal block side remained stable until the goaf edge was between 10-15 m away. At this stage deformation and failure of coal rib allowed lowering of the roof. This meant that the first stage of roof tilting was caused by the chain pillar yielding to a depth of 4.5 m. This tilting was active while the pillar was formed and progressed until extraction of coal took place.

A second stage of roof deformation occurred which was influenced by the goaf distance from the heading. In this instance the roof remained stable during extraction until 10-15 m remained to be extracted from the fender. Then a sudden jump in roof deformation from 4 mm to 40 mm occurred in the roof adjacent to the rib (see Figure 25). This rate of deformation could lead to the failure of the roof.

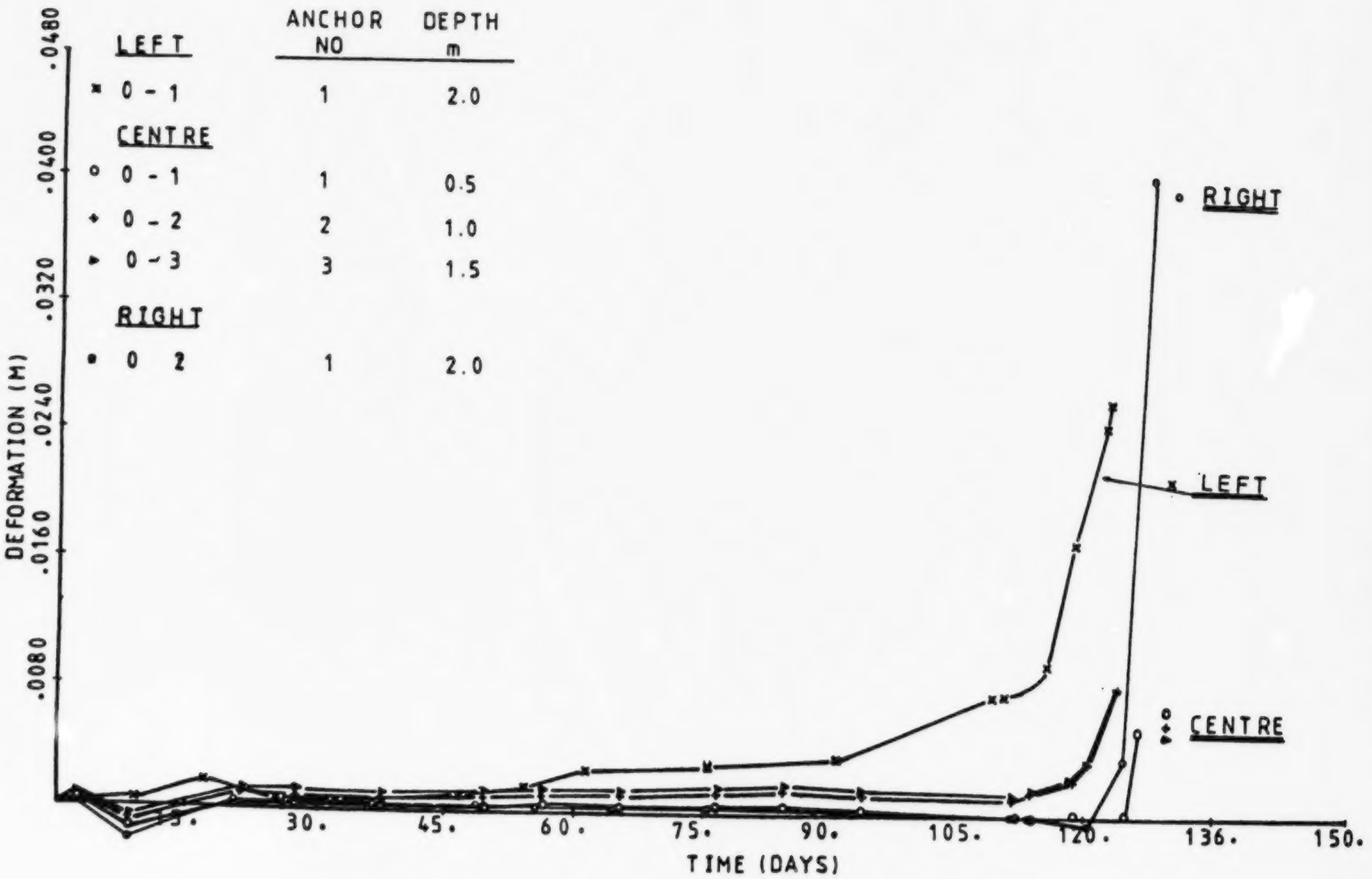


Figure 25. Roof Deformation at Station E3 in the Belt Heading.

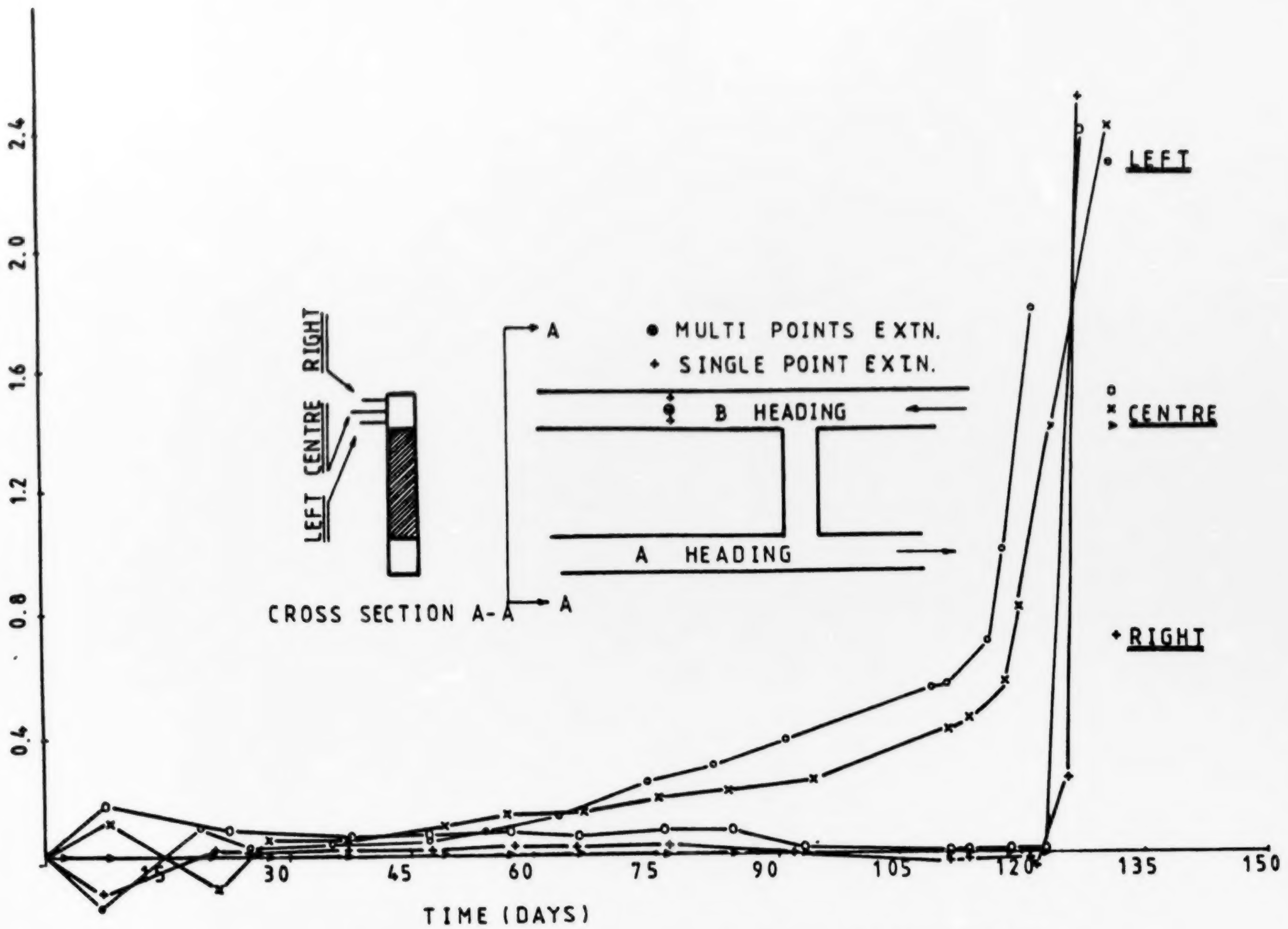
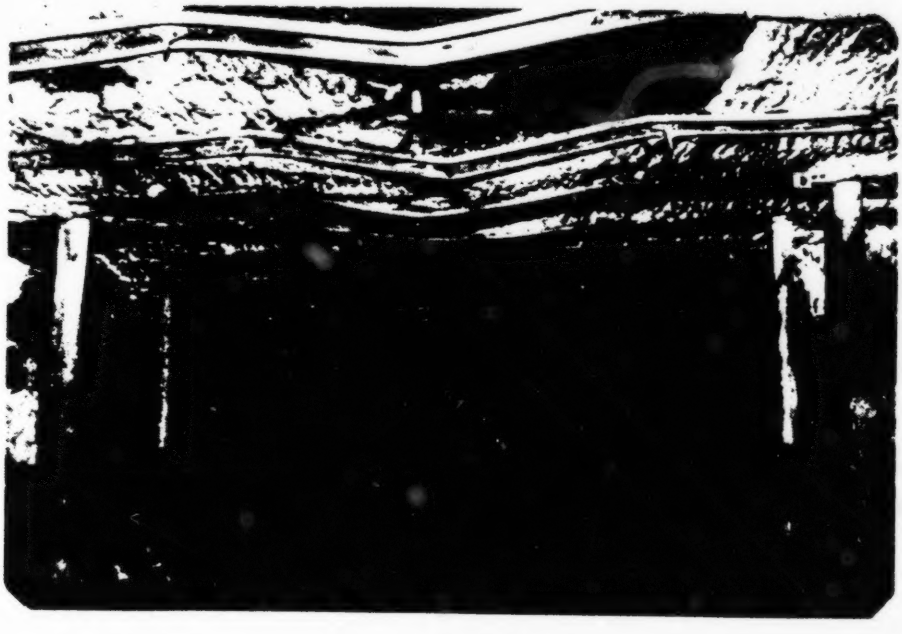


Figure 26. Roof Strain at Station E3 in the Belt Heading.

(a) Rib Guttering



(b) Roof Slabbing

PLATE 2.

6. ESTIMATING THE FACTOR OF SAFETY OF THE PILLARS

The following calculations are an empirical method of assessing the stability of the Wongawilli panel development pillars at Coalcliff Colliery.

This method was developed for the South African coal mining industry(1) using data gathered from 125 case histories of both pillar failure and pillar stability. The depth of cover however was less than 220 m in all cases and as such several of the parameters used in the method may not be applicable to the mining conditions at Coalcliff Colliery where the depth of cover is 480 m.

The parameters which are contentious are K, α and β which are used in the formulae for estimating pillar strength.

$$\text{Strength (MPa)} = Kh^{\alpha} w^{\beta}$$

where h = the height of the pillar (m)
w = the width of the pillar (m)
K = 7.200 (MPa)
α = -0.66
β = 0.46

K, α and β were derived by complex statistical analysis of the information provided to the South African researchers. It is hoped that the work undertaken during the ACIRL Pillar Stability research program will aid in determining the values of these parameters or those of other appropriate formulae under Australian coal mining conditions.

1. Primitive Stress

$$Q = 0.025\ H\ \text{MPa}$$
$$= 0.025 \times 480\ \text{m} = 12\ \text{MPa}$$

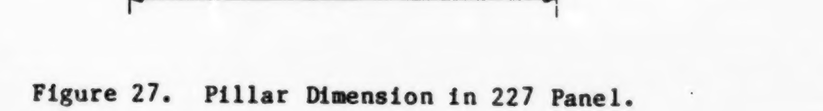


Figure 27. Pillar Dimension in 227 Panel.

2. Pillar Load

$$p = 25 \frac{H \times A}{A_p}$$

$A = A_m + A_p$

where A_m = Bord Area

A_p = Pillar Area

$$A_p = 57 \text{ m} \times 17.9 \text{ m}$$

$$= 1342.5 \text{ m}^2$$

$$A = 62.5 \times 24$$

$$= 1500 \text{ m}^2$$

$$p = 25 \frac{480 \times 1500}{1342.5} = 13.4 \text{ MPa}$$

3. Pillar Strength

$$\text{Strength} = K\, h^{\alpha}\, w^{\beta}$$

$$= 7.200 \frac{w^{0.46}}{h^{0.66}}$$

$$= 7.2 \frac{17.9^{0.46}}{2.7^{0.66}}$$

$$= 14.1 \text{ MPa}$$

where

α = -0.66

β = 0.46

h = Pillar height (m)

w = Pillar width (m)

4. Safety Factor

For the existing pillar dimensions.

Safety factor $$S = \frac{\text{pillar strength}}{\text{pillar load}}$$

$$S = \frac{14.1}{13.4} \text{ MPa} = 1.05$$

$\therefore$ Safety Factor equals 1.05 for a pillar 17.5 metres in rib to rib width, 57 metres in length, at 2.7 metres working height, and depth of workings 480 m.

This safety factor appears to compare reasonably well with the results of the monitoring of deformation of the pillars. The analysis of the monitoring indicated that the pillars were yielded up to a depth of 4.5 m during the development phase of the panel extraction. This indicates that a stable 8.5 m thick core of unyielded coal existed in the pillar. Considering this result it can be assumed that the empirical calculations underestimated the stability of the pillar; however the empirical calculations are based on large areas of bord and pillar workings. In the case analysed at Coalcliff a single line of pillars existed. Under these conditions the pillar will not be evenly loaded.

7. CONCLUSIONS

General Conditions

1. The Wongawilli method of coal extraction adopted at Coalcliff Colliery is well suited to the conditions prevailing at this mine. The panel entry pillars were found to offer long term stability during the development phase of mining and remained stable during the fender extraction operation.

   The current pillar and panel layout has been developed from a number of years experience and would appear to have no major problems. The roof was well controlled in both first workings and during the split and fender operations. Production from the panel was carried out in an efficient manner with operations such as belt and continuous miner moves being undertaken on a cyclic basis.

   Recovery of coal from the panel was excellent. In general the only coal that was left was in the form of stooks either side of the belt heading and in the goaf edge of the fender.

Stress and Caving Environment

2. The maximum mining induced stress recorded was 24 MPa (i.e. twice the estimated virgin stress). This was indicated as being the peak abutment stress which was located 15 m to 20 m in advance of the goaf edge.

3. The profile of mining induced stress in the pillar occurred in four phases. During the development of the panel virtually no stress pick-up was indicated from the preset value of 4 MPa. Once pillar extraction commenced there was a gradual pick-up of 3 MPa of stress while the goaf edge progressed from 280 m to 60 m away from the pillar. There was then a dramatic increase in stress of 18 MPa.

   This peak of 24 MPa total stress was located 15 m to 20 m away from the goaf edge during the extraction of the adjacent fender. When this fender extraction was completed the stress on the coal up to 10 m away from the goaf decreased dramatically to a value of 4 MPa. Split and fendering of this coal was therefore undertaken in a destressed zone.

   These results prove the theory on which the Wongawilli system of extraction is designed, that is, to create an area of low stress so coal extraction can be carried out with reasonable safety and speed.

4. The profile of mining induced stress in the solid block of coal that was eventually extracted was indicated as being slightly different to that of the pillar. There was a gradual increase in stress during pillar development once extraction took place 280 m to 60 m away from the site. When the goaf was 60 m away the stress then began increasing quite rapidly as the goaf approached.

   This stress profile was far more gradual than for the pillar area as the solid block of coal would attract a greater load, being the more competent of the two locations.

5. The uniaxial strength of the Bulli coal seam has been determined as 22 MPa. From the stress measurements this value was slightly exceeded with peak abutment of 24 MPa.

6. A yield zone to a depth of 4.5 m into the pillar was found. This would leave a core 8.5 m thick which would offer long term stability.

7. The strain and displacement recorded were slightly higher on the belt heading side than the return heading side.

8. When displacement occurred, the rate of deformation of the solid block of coal was more gradual than that of the pillar side which showed a rapid increase in deformation once the goaf edge was within 50 m of the monitoring side.

Roadway Deformation

9. A distinct tilt of the roof towards the pillar side was detected. This was indicated in both the return and belt and track roadway.

Estimating Pillar Stability

10. From an empirical method developed for designing pillars it was shown that the panel pillar had a factor of safety of 1.05, where a value below 1.00 indicates instability.

8. REFERENCES

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Rock Mechanics in Coal Mines.

9. ACKNOWLEDGEMENT

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Automation in Coal Mining

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A study of the 21st Century energy situation shows that coal must be the principal fuel, gradually followed by the renewable fuels which require fossil fuel to make and build the equipment. For a stable world the developed countries must help the less developed by providing all the tools necessary for self production of a decent standard of living, and to avoid world war all countries must necessarily converge on a per capita energy usage about equal to the present world average per capita figure of 1·5–2 tons of coal equivalent. As oil runs out a substitute liquid fuel will have to be made from coal and from biomass because oil is uniquely suitable for road, sea and air transport and for agriculture.

Coal can be mined without men going underground by directed drilling and by Telechirics—hands at a distance.

In Telechiric mining, the coal would be won by conventional mining machinery but the human miners would erect, operate, maintain and repair this machinery by sitting in a control room on the surface and controlling telechirs which could move about the mine and would have mechanical hands which would respond exactly to every movement of the human master's hands. He would have touch and force feedback and three dimensional vision so good that he could use his trained craft skill of hands and eyes as though he were down the mine.

Table 1. World fossil fuel reserves and resources units 10^9 TCE

	Reserves	Total resources	Resources recoverable by new methods
Coal	1300	10,800	21,000[1]
Oil	166	350	700[2]
Natural gas	82	200	500[3]
Shales and tar sands	460	900	10,000[4]
Uranium	17	43[6]	5000[5]

Notes

[1] Assuming telechiric mining is developed to win seams down to 1/2 m thick, at depths up to 3000 m and undersea distances up to 100 km from the shore.

[2] Assuming means are found of obtaining 90 per cent of all deposits.

[3] Assuming all natural gas is recovered and used from the most remote deposits.

[4] Assuming practical means are found for extracting all oils of significant concentration.

[5] Assuming successful breeder reactors and the extraction of U from granite.

[6] These figures are taken from 'World Uranium Resources', Energy World, June 1978, p. 2; assuming thermal reactors for which 1 TU ~ 10,000 TCE, total resources at costs up to $130/kg U.

The Future Importance of Coal

Everyone who looks into man's energy needs in the 21st Century agrees that coal must play an increasing part since it is by far the most widespread source of fossil fuel energy. Table 1 gives a comparison of the estimated resources of various fuels. The geological conditions required to lay down a seam of coal are very much simpler than those required to store liquid or gaseous hydrocarbons over millions of years.

Compared with nuclear energy, coal has the fundamental advantage that it can be stored in small or large quantities and converted directly into low grade heat for water heating or space heating with thermal efficiencies of the order of 80 per cent. If one converts the fuel, whether nuclear or coal, first into electricity and distributes it, one has not only the enormous capital cost of the electric plant and distribution system but also an overall thermal efficiency not much better than 25 per cent.

However, coal suffers from one serious disadvantage. At the present time it can only be brought to the surface by skilled miners who spend their whole working lives underground. This is not only unpleasant and dangerous but also requires long time-wasteful journeys underground. It seems most likely, therefore, that it will be more and more difficult to persuade people to win coal in this way as the working conditions in other industries improve. One can, therefore, conclude that it is worth devoting research and development effort and sums of money comparable to those we are spending on Nuclear Energy or Space investigations on the study of a method for winning solid coal without men going underground.

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Proposals have been put forward for underground combustion and experiments have been done on underground gasification with partial combustion with air or oxygen. Both these systems, however, require men to work underground to set up the apparatus and in the case of combustion to operate it. In the case of underground gasification when one hole has been burned out it would be necessary for men to go down and set up the next one, thus the work of these two methods would be much more dangerous than present mining systems. Moreover, the coal is converted underground into low grade gas or heat which must then be used locally to produce electricity with all the inefficiency and high capital cost of an electric distribution system. Since the power station has to be at the seam it is difficult to use the efficient combination of electricity generation and pass-out steam heating such as we use at Battersea and which is increasingly being used in all other countries but Britain.

If coal is brought to the surface in lump form it can not only be distributed and stored all over the country but also it is available for other purposes such as making coke for blast furnaces, smokeless fuels for domestic use and for use in making synthetic liquid fuel and synthetic fuel gas. Both the gas industry and the petroleum industry are expecting to use coal as their principal raw material when the oil and natural gas become exhausted.

Outline of a World Energy Policy

In my book *The Engineer's Conscience** I have gone in detail into the necessary requirements as regards energy policy if we are to have a stable peaceful world in the next century. Here I will only summarize the arguments in order to confirm what I said in the first section about the future importance of coal.

The essential facts of the present energy situation are:

(i) The developed countries depend on the consumption of 5 or 6 tons of coal equivalent for every person every year. This is about 30 times the energy equivalent of the food that a healthy adult eats so that one can say that they have 30 energy slaves for each person. On the other hand every engineer knows that more than two-thirds of this energy is wasted as far as the full satisfaction of the individual's needs are concerned. One outstanding example of this waste is the above mentioned use of coal or oil to produce electricity with an overall thermal efficiency of some 25 per cent when the use of combined heat and power systems could immediately halve the energy consumption with no drop in the benefits to the user. Another one is plastic packaging materials and a third is built-in obsolescence. If one made consumer goods such as cars which lasted three times as long one would require only 20 per cent more energy in the first manufacture. It has been calculated that if a housewife bicycles to the shops she uses 1/1000 energy as if she drives in a large car.

(ii) At the present time the population of the underdeveloped countries is two-thirds of that of the whole world and this will rise to more than three-quarters as the present rates of population growth are extended for the next 30 years, during which period the overall world population will double from the present figure of about 4000 million. In these underdeveloped countries the average energy consumption is less than ½ ton coal equivalent per head per year and this is mostly in the form of wood which is burned for cooking so that as the human population goes up the population of trees is falling disastrously. The desert areas of the world are growing every year.

Careful analysis of the conditions for world stability in the next century leads to the following conclusions:

(i) It is just possible to give 8000 million people a fully adequate standard of living (the ability to earn a good diet for all the family and a comfortable home without excessive drudgery) and an adequate education within the earth's renewable resources. However, it would certainly not be possible to do this for 16000 million people. Thus it is essential that we find means of levelling off the world's population within one generation. *The only possible humane way to do this is to give a decent standard of living and a decent education to all the 8000 million people who will be on the earth by the year 2010.*

(ii) So long as one group of people are living at a very much lower standard of living than another group, while the latter are wasting the earth's limited resources there can never be a stable world peace. This conclusion has been reached by many people. It is not that the underdeveloped countries could attack the heavily armed developed ones but that the world tension created by the envy is bound to lead to an outbreak of war between the highly developed Great Powers. It is always easy to stir up trouble among people who are fundamentally envious of a richer group. Therefore, the second conclusion is that *the gap between the standard of living of the developed and the underdeveloped countries has to be essentially removed early in the next century if our civilization is not to destroy itself by the use of its nuclear armaments.* It is, of course, well known that not only the countries which are the recipients of these intercontinental missiles but all those in the same hemisphere will suffer catastrophic damage to life, especially to future generations from the radioactive fallout if such war breaks out.

(iii) It is also well known that the underdeveloped countries are not in a position to help themselves unaided out of their dilemma, requiring as it does the use of expensive oil and the investment of heavy capital and equipment so that conclusion (iii) is that *unless the developed countries devote a substantial part of their research and development effort and their capital investment to the needs of the underdeveloped countries their own future is catastrophic.*

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*M. W. Thring, The Engineer's Conscience, Northgate Publishing Co., London (1980).

(iv) At the present time the official policy in all the developed countries is to have a further increase in the energy consumption *per capita*. The 'high growth' people want 4 per cent p.a. which would correspond to a 50 fold increase in a century. The low growth people are prepared to settle for 1 or 2 per cent. However, if we eliminate the gap between the developed and the underdeveloped countries then even zero growth in the developed countries means that everyone in the world would be using that used in the developed countries at the present time, which is about 5½ Tons Coal Equivalent per year (the U.S. figure is more than twice this). Since the world population will inevitably double and the present world *per capita* average figure is about 1·8 TCE/year-head this would mean that the total world consumption of energy would be six times the present figure. This is a totally unrealistic figure because even coal would be exhausted in a few decades and moreover the CO_2 content of the atmosphere would rise to unacceptable levels from the point of view of the well known 'greenhouse' effect. The fourth inescapable conclusion is that *the developed countries must come down in their energy consumption* per capita, *over the next 30 or 40 years, to a figure of the same order as the* per capita *world average figure of around 2 TCE/year-head.* This does not sound so bad when it is put in terms of a reduction in consumption in Britain of some 3 or 4 per cent/year every year for the next 40 years although the U.S.A. would have to have a reduction of about twice this (see Figure 1).

(v) *The premium fuels, electricity, oil and natural gas will have to be brought down considerably faster than this.* In the case of electricity it is thermodynamically ridiculous to burn coal, oil or uranium nuclei in a power station to make electricity (at an overall thermal efficiency of 25 per cent) and then use this electricity to heat water or rooms which could be done directly with a thermal efficiency of 70–80 per cent. The only sensible long term scheme for towns or regions close to power stations is to convert existing power stations to coal firing (with greatly improved gas cleanliness) and use pass out water heating in the cities. This would produce exactly the same result with less than half the primary fuel input. For other regions the most efficient forms of heating are direct coal firing or electrically operated heat pumps. The consumption of oil and natural gas in the developed countries must be reduced at 7–8 per cent/year because these fuels are in very short supply and are uniquely suited for certain purposes so that when they are exhausted *Synthetic Liquid Fuel and substitute natural gas will have to be made from coal or bio fuels.* The less developed countries urgently need liquid fuel for agriculture and road transport but it is being used up very rapidly and wastefully in the developed countries.

(vi) *In the long term only those developments are valid which can be supplied to all peoples of the world.* Thus the energy needs of the rural areas cannot be supplied by central electric generating stations fired in any way because of the energy requirement to set up the distribution systems.

(vii) *Coal must therefore be the major fossil fuel of the 21st Century* and if suitable mining methods are developed could probably supply the greater part of the 16000 million tons/year needed to give the 8000 million people a decent standard of living. However, even coal must in the long term be regarded as a capital resource and by the time it is exhausted we must have spent enough of it on

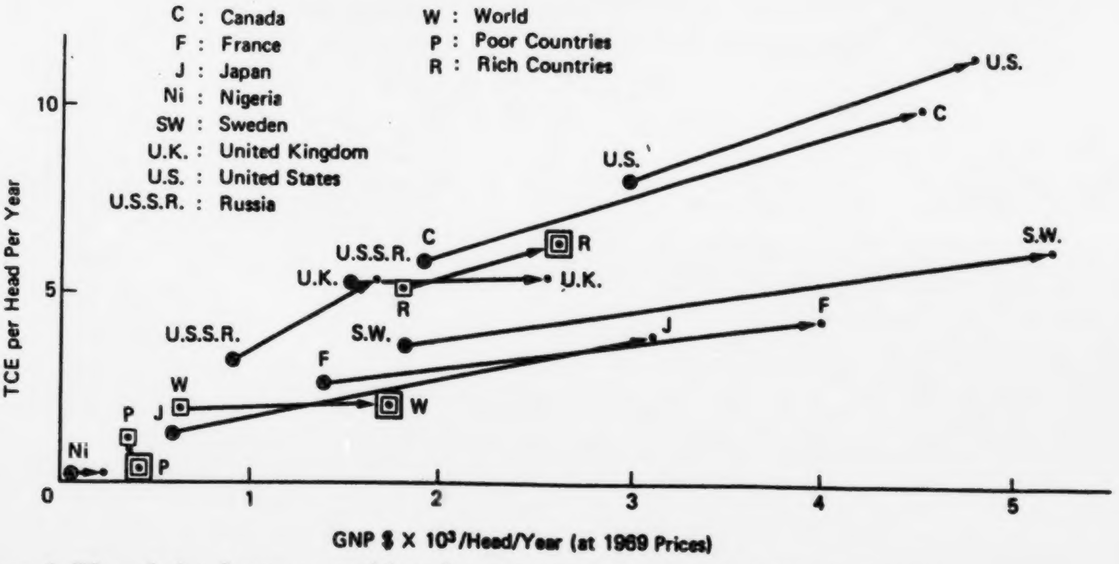

Figure 1. The relation between wealth and energy consumption of various countries

installing the equipment necessary to provide substitutes from the renewable energy resources, namely solar (direct and via biofuels) wind, tidal, hydro, wave and geothermal.

These problems and their solution are summarized in Figure 2.

Telechiric Mining

One way of bringing coal to the surface without men going underground would be to have a steerable drill which could be made to drill along a coal seam so that the coal was pumped to the surface in a water stream in the same way as drilling mud is at the present for an oil well. This could be drilled down to the seam and then steered along the seam with a series of holes being drilled from one vertical shaft and the drill withdrawn between each one. It is possible to devise the steerable drill with pressure put on from the front end by making the head in two parts joined together by hydraulic rams as shown in Figure 3. It is also possible to put feeler devices or other types of sensors on the drill head so that the drill can be steered to remain in the seam by the human controller on the surface who receives signals from these devices.

This type of steerable drill mining has considerable interest for the very thin seams such as the best coking coals of the Durham area which are not economic to mine by present methods although in the old days they were mined by hand with the human miner lying on his side as he hacked at the coal. The percentage of the coal which could be recovered is not very high as one would drill round holes through the seam and they could not be located very close together. Nevertheless it does offer a method of winning coal in very thin seams which would well make it worth investigating.

However, a more versatile system is offered by the work on Telechirics which has been carried out over the last 30 years, particularly in America and more recently in France by those interested in the remote handling of highly radioactive materials and in remote manipulation in space applications. More recently a great deal of interest in this field has come from the interest in drilling for oil from the bottom of the sea for carrying out operations on wells drilled from platforms in the sea.

Telechirics literally means *hands at a distance* and it has already been developed to the point where a reasonable degree of manipulative craft skill can be exercised remotely. The best known example is the mechanically linked hands which the operator used inside a *cave* to manipulate radioactive material. These hands are subject to problems of friction, inertia and play all of which can be greatly improved by a power system. They also require the operator to look at his work through a thick window so that his vision is considerably worse than it would be if he was on the spot.

A great deal of work has been done on power systems and mechanical master/slave arm systems are available on the market incorporating a measure of force feedback so that the human can feel when the hand is grasping an object or the weight of the object he has picked up. These are at present very expensive because they are manufactured in very small quantities.

Nevertheless, it is possible to conclude that without discovering any new basic principles it is possible to design a mining telechir such that a human miner on the surface can carry out the essential parts of any task which he would normally do on the spot down a mine. We can thus define telechiric mining as follows:

> The human miner carries out any task that he would do down the mine such as controlling machines to cut roadways, the erection of supports, the installation of coal mining and transport machinery, its operation, diagnosis of breakdowns and repairs with sufficient skill as though he were on the spot down the mine (see Figure 4).

It is often said that automation of coal mining is sufficient to solve the problems of the future by itself. It is true that excellent work is being carried out on automation and we can envisage a coal mine in which coal cutting and steering the cutter and the coal conveying are all fully automated, together with the movements of the supports. Nevertheless it is an unfortunate law of engineering that the more one automates the more ingeniously the system finds new ways to break down for which no allowance has been made. *These breakdowns require the adaptability, observational ability and skill of a human craftsman to locate the fault, diagnose exactly what is wrong and repair it.* Moreover, the general trend of result of automation and mechanization is to reduce the proportion of coal which is mined and to increase the dust thrown up by the more rapidly cutting machines. It follows that the future of coal mining requires the full combination of automation with telechirs, so that men can use their skill and intelligence to get the best out of the machines without subjecting their bodies to discomfort and risk.

In the first instance we can take a telechiric mine as being operated by three categories of machines:

(i) The conventional machines that cut the coal, cut the roadways, insert props, convey coal and convey machinery.

(ii) A number of telechirs (see model in Figure 5), that is machines with senses, arms and hands, which are in complete communication with the humans on the surface so that the humans can see what they

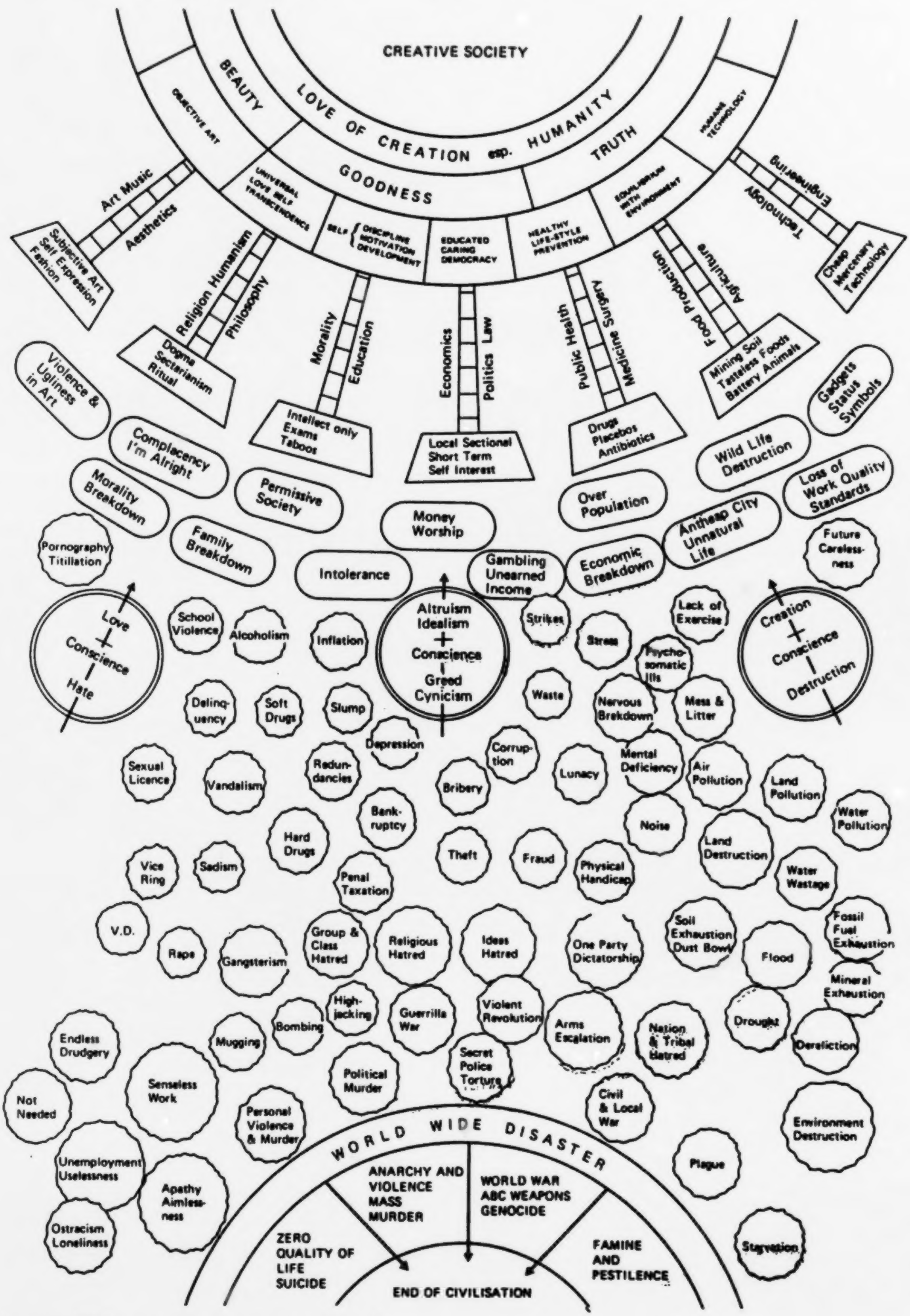
CREATIVE SOCIETY
LOVE OF CREATION esp. HUMANITY
BEAUTY
GOODNESS
TRUTH
OBJECTIVE ART
HUMANE TECHNOLOGY
UNIVERSAL LOVE SELF TRANSCENDENCE
SELF { DISCIPLINE MOTIVATION DEVELOPMENT
EDUCATED CARING DEMOCRACY
HEALTHY LIFE-STYLE PREVENTION
EQUILIBRIUM WITH ENVIRONMENT
Art Music
Aesthetics
Subjective Art Self Expression Fashion
Religion Humanism
Philosophy
Dogma Sectarianism Ritual
Morality
Education
Intellect only Exams Taboos
Economics
Politics Law
Local Sectional Short Term Self Interest
Public Health
Medicine Surgery
Drugs Placebos Antibiotics
Food Production
Agriculture
Mining Soil Tasteless Foods Battery Animals
Engineering
Technology
Cheap Mercenary Technology
Violence & Ugliness in Art
Complacency I'm Alright
Morality Breakdown
Permissive Society
Family Breakdown
Money Worship
Intolerance
Gambling Unearned Income
Over Population
Economic Breakdown
Antheap City Unnatural Life
Wild Life Destruction
Gadgets Status Symbols
Loss of Work Quality Standards
Future Careless-ness
Pornography Titillation
Love + Conscience – Hate
Altruism Idealism + Conscience – Greed Cynicism
Creation + Conscience – Destruction
School Violence
Alcoholism
Inflation
Strikes
Stress
Lack of Exercise
Psycho-somatic Ills
Delinq-uency
Soft Drugs
Slump
Waste
Nervous Breakdown
Mess & Litter
Depression
Sexual Licence
Vandalism
Redun-dancies
Corrup-tion
Bribery
Lunacy
Mental Deficiency
Air Pollution
Land Pollution
Bank-ruptcy
Noise
Water Pollution
Hard Drugs
Theft
Fraud
Land Destruction
Vice Ring
Sadism
Penal Taxation
Physical Handicap
Water Wastage
V.D.
Rape
Gangsterism
Group & Class Hatred
Religious Hatred
Ideas Hatred
One Party Dictatorship
Soil Exhaustion Dust Bowl
Flood
Fossil Fuel Exhaustion
Mineral Exhaustion
High-jacking
Guerrilla War
Violent Revolution
Endless Drudgery
Mugging
Bombing
Arms Escalation
Nation & Tribal Hatred
Drought
Dereliction
Secret Police Torture
Political Murder
Senseless Work
Not Needed
Civil & Local War
Personal Violence & Murder
Environment Destruction
Unemployment Uselessness
Plague
Apathy Aimless-ness
Ostracism Loneliness
Starvation
WORLD WIDE DISASTER
ANARCHY AND VIOLENCE MASS MURDER
WORLD WAR ABC WEAPONS GENOCIDE
ZERO QUALITY OF LIFE SUICIDE
FAMINE AND PESTILENCE
END OF CIVILISATION

Figure 2. 'Either we go up or we go down'

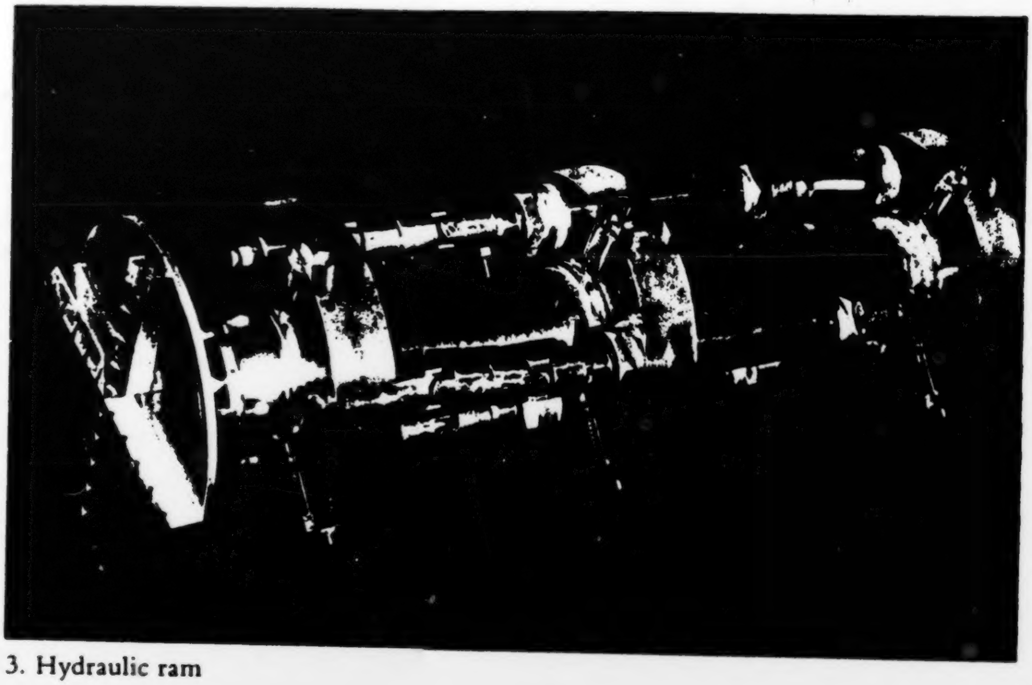

Figure 3. Hydraulic ram

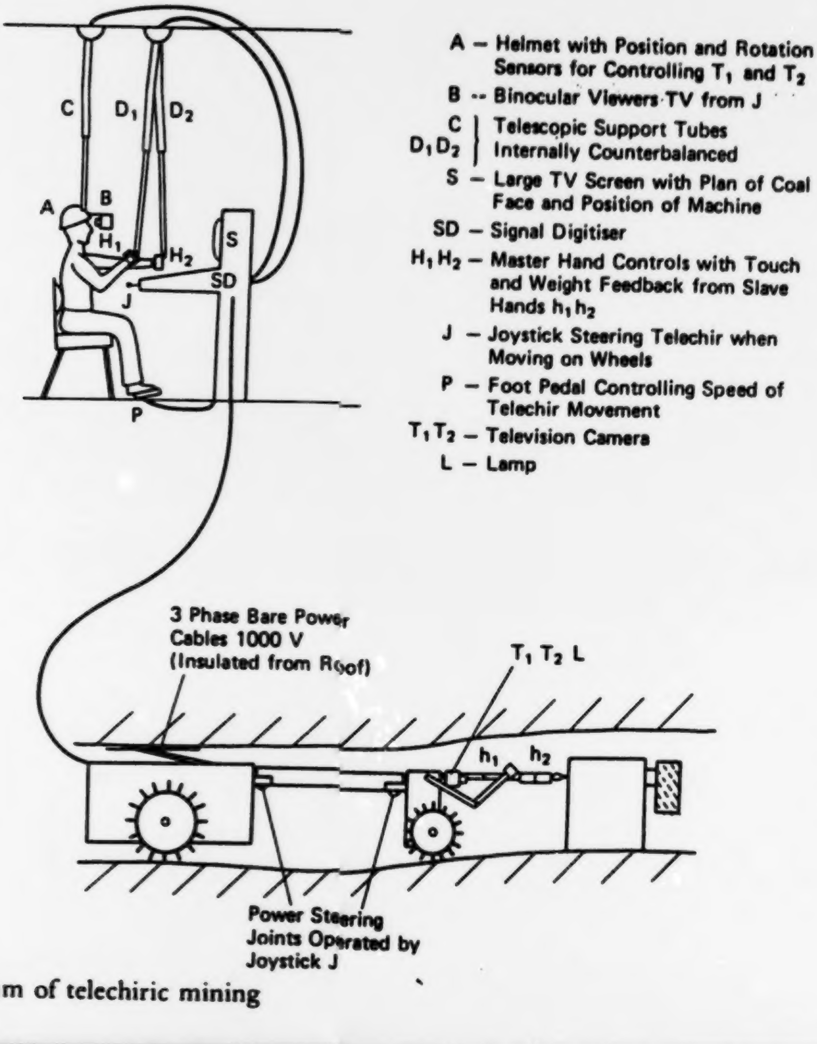
C
D_1
D_2
A
B
H_1
H_2
S
SD
J
P
3 Phase Bare Power Cables 1000 V (Insulated from Roof)
T_1 T_2 L
h_1
h_2
Power Steering Joints Operated by Joystick J
A – Helmet with Position and Rotation Sensors for Controlling T_1 and T_2
B -- Binocular Viewers TV from J
C, D_1D_2 – Telescopic Support Tubes Internally Counterbalanced
S – Large TV Screen with Plan of Coal Face and Position of Machine
SD – Signal Digitiser
H_1H_2 – Master Hand Controls with Touch and Weight Feedback from Slave Hands h_1h_2
J – Joystick Steering Telechir when Moving on Wheels
P – Foot Pedal Controlling Speed of Telechir Movement
T_1T_2 – Television Camera
L – Lamp

Figure 4. Diagram of telechiric mining

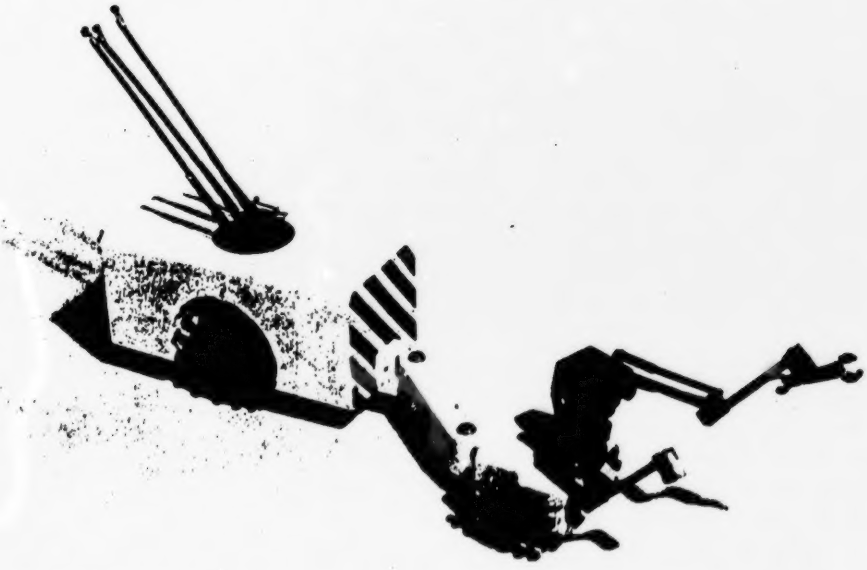

Figure 5. Model of a mining telechir

would see if they were down the pit working at a given spot and have sufficient feedback of touch and force sensitivity from the machine's arms to the human's arms so that they can carry out craft skills and handle tools and the controls of other machines. Most of the telechirs would be attached to independent bodies which could be made to move about the mine at a reasonable speed.

It is a considerable advantage of the principle of telechiric mining that these bodies can be much better adapted for movement in a very shallow roadway than a human being who has to go on hands and knees, while at the same time their arms can be very much stronger. Some of the telechirs would be attached so that the human on the surface could use these arms for example to replace a cutter pick, the arms and the TV cameras being placed on a strong arm attached to the machine so that they can be pushed into the required position. The sensory observations required to steer the machine to follow the seam would be provided by various types of equipment on the machine so that the human driver on the surface could steer the machine with better information than he would have even if he were actually riding on it. The mobile telechirs would be used in the jobs of erecting the machines and diagnosing and repairing breakdowns at any point in the system. The two-way communication to the telechirs would be provided by coaxial cable or fibre optics with moderated laser beam or by closed circuit microwave radio. All power would be three-phase electric, 1000 volts or even more to reduce weight of copper. Bare wires could be used as the outside of the telechirs could be insulated in case they lurch against the wires.

I am often asked what happens when a telechir breaks down. The simple answer is that it would either be repaired by another telechir down the pit or be pulled out of the pit by another telechir and repaired on the surface. In any case telechirs will come to the surface every three months for a complete overhaul. They are made of heavy steel plate so that they are very much more robust than the humans they replace and they are powered by 10 kW or even 50 kW motors. In a total disaster telechirs can be abandoned without compunction in the pit.

(iii) Control room on the surface (see Figure 6(a)). All the miners operating the pit would sit in a single control room on the surface and there would be a large map showing the position of the machines in the pit at any given time. Each miner operating a telechir would sit in front of a control panel which has a joy-stick for moving the telechir about the pit and has two glove type hand controls into which he inserts his hands. When he is using these the mechanical hands of the telechir follow his hand movements and he receives back force sensations and touch sensations so that he actually sees and feels the tool or job which he is doing down the pit as though he were in front of it. The mechanical hands of the telechir can have force amplification so that they can grip very powerful tools and also have continuous rotation so that they can screw nuts up without a spanner. In order to complete the feeling of the miner being down the mine he can move his head and body about in his seat and the counter balanced helmet would convey his movements to the shoulders and head (TV cameras) of the telechir, thus he could look at a job from all sides. Ultimately perhaps we may be able to do remote moving laser holography in which case the sensation of seeing the three dimensional image in front of him in which the image of the telechir's hands will appear where

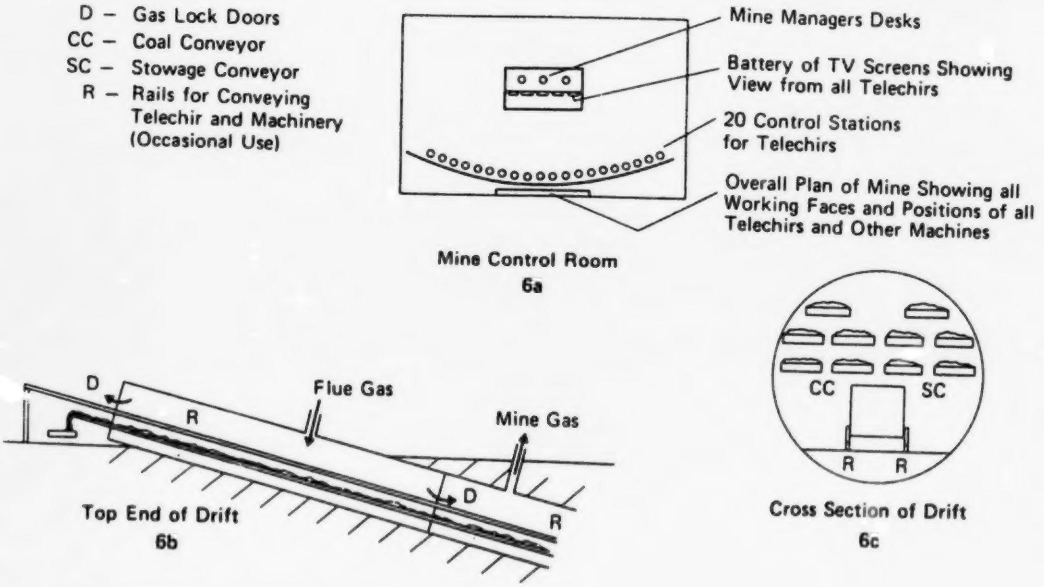
D – Gas Lock Doors
CC – Coal Conveyor
SC – Stowage Conveyor
R – Rails for Conveying Telechir and Machinery (Occasional Use)
Mine Managers Desks
Battery of TV Screens Showing View from all Telechirs
20 Control Stations for Telechirs
Overall Plan of Mine Showing all Working Faces and Positions of all Telechirs and Other Machines
Mine Control Room
6a
D
Flue Gas
R
Mine Gas
D
R
Top End of Drift
6b
CC
SC
R
R
Cross Section of Drift
6c

Figure 6. Telechiric mine layout details

his hands are. In the control room there will also be geologists, senior mining engineers and the pit manager who can take over any telechir at any time when their expertise is required but they can also have in front of them at their desks TV screens showing what all the telechirs are seeing at any given time.

The Advantages of Telechiric Mining

No Ventilation

Once it has become possible to carry out all the mining operations and use all the mining machinery by means of the manipulation of electrically powered telechirs it is no longer necessary to ventilate the mine, thus less than half the present underground working will be necessary. This now consists of a double system with two shafts and a complete flow and return for air from every working face. A great part of the work underground is concerned with maintaining adequate ventilation at all points and making sure that dust levels are kept down to reduce the danger of pneumoconiosis and that methane coming from the coal as it is cut never builds up to a dangerous level. The fan power for ventilation is also very considerable. It would not be necessary to put any oxygen or air down the mine at all and thus the whole mine can operate in its own atmosphere of methane and CO_2 This means that there is no fire hazard and none of the machinery has to be flameproofed making it considerably lighter and easier to design. At present the heat generated by machines such as coal cutters which may have up to 400 h.p. is removed by the air circulation and spread through the pit. This is, of course, a very inefficient way of shifting heat using fans driven by hundreds of horse power on the surface, whereas comparatively small fans fixed on the machinery could circulate the local gas or alternatively water cooling could be used to spread heat and it would not matter if the water was boiled so that clouds of steam were emitted and the machine ran at boiling point temperature. Not only would one save all the power at present used to ventilate a mine but by using the system shown in Figure 6(b) it would be possible to burn the methane as a fuel at the surface. This system isolates the mine atmosphere from the outside atmosphere by a double lock system of doors, the space between the doors is filled with inert combustion gases (CO_2 and N_2) from a surface boiler at positive pressure so that it leaks out of both doors into the other two systems.

No Man Transport

In the present mining system the miners may take more than 1 hour going down the shaft and reaching the coal face so that their period of work is very short and it is also necessary to provide expensive man carrying systems in the shafts and underground roadways. In a telechiric mining system the men would merely have to go to their work place on the surface where they would sit in front of the master apparatus and control the telechir to move about the mine or to do its skilled job with its mechanical hands. The telechirs would come to the surface perhaps once every three months for overhaul so that there would have to be conveying machinery which would also be needed for taking down main machines but this would not be in use every day and would not need to be provided with man riding comforts such as seats.

Lighting and Communication

Each telechir would carry its own power lighting system directly related to its TV camera so that it could see exactly whatever it wanted wherever the telechir went so that there would be no need for an overall lighting system in the pit. On the other hand there does have to be a three-phase power system which would be installed with bare cables fixed to the wall or roof with insulators and there would also have to be a microwave communication system to enable men on the surface to receive TV pictures from their appropriate telechirs and to communicate the other necessary controls to the telechir. Each telechir would, in principle, consist of a body designed for movement in the thickness of the coal seam carrying two mechanical arms with hands. They might be as shown in Figure 5 with a trunk carrying the *shoulders* and *eyes* which can be swivelled about the main body to correspond to the movements of the shoulders and head of the controller on the surface. In this way complete three dimensional vision of a task can be obtained in the same way as a craftsman obtains it when he is looking directly at the job.

A Pit Designed Around Telechirs

So far I have spoken as if a coal mine with telechirs would use the present kind of mining system, e.g. the long wall system with armoured face conveyors, advancing hydraulic pit props and a rotary drum shearer moving backwards and forwards down the coal face as it advances. However, it is clear that once a pit is designed to make full use of the freedom given by not having to have men down it there are numerous other advantages. As shown in Figure 7 we can envisage a coal face which consists of a large number of in seam cutters linked together advancing away from the main roadway. As they go forward all except the one on one end or in the centre stow material behind them. This material is both washery refuse and additional sand or ground rock. This is packed in behind a row of steel plates which follows the miners, thus the so-called *slag tips* on the surface which are in fact washery refuse would be completely eliminated so that the surface effect of a mine would be comparatively small instead of the hundreds of acres of tip which it has at present. Moreover, this stowage would largely eliminate surface subsidence which is one of the most serious consequences of mining at present and which makes it impossible to take coal from under towns or rivers. The material would be brought down either in a pipe as a water slurry as is done in Poland or separate belt conveyors could bring it down. The end one of the cutters would construct behind it a permanently supported roadway through which the conveyors would follow it, one taking the coal out and one to bring the stowage material in. The in-seam cutters would be equipped with automatic devices for sensing the roof and floor of the seam so that they would follow the seam automatically. They would also have additional devices for using other means of detecting the coal which would feed to an operator whose job it was to check the steering and override the automatic control when necessary. Any breakdown or need for replacing cutter picks would be signalled to this operator who would then ask his colleagues working a telechir at the coal face to use his telechir to find the fault and repair it.

Since men do not have to travel daily to the coal face there is no reason why the mining activities

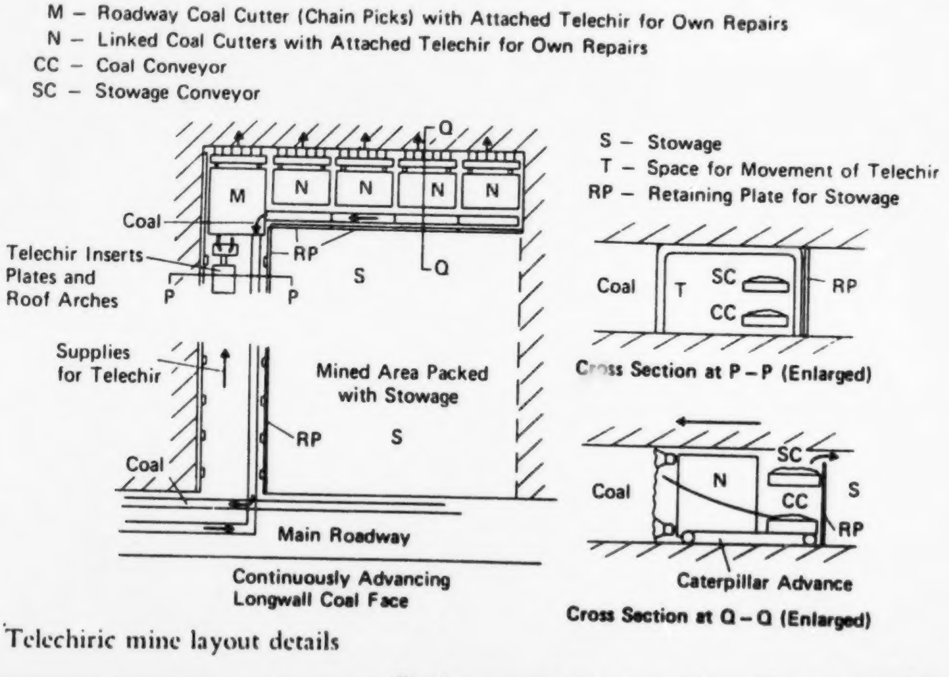
M – Roadway Coal Cutter (Chain Picks) with Attached Telechir for Own Repairs
N – Linked Coal Cutters with Attached Telechir for Own Repairs
CC – Coal Conveyor
SC – Stowage Conveyor
S – Stowage
T – Space for Movement of Telechir
RP – Retaining Plate for Stowage
Q
M
N
N
N
N
Coal
Telechir Inserts Plates and Roof Arches
RP
S
Q
P
P
Supplies for Telechir
Mined Area Packed with Stowage
RP
S
Coal
Main Roadway
Continuously Advancing Longwall Coal Face
Coal
T
SC
CC
RP
Cross Section at P – P (Enlarged)
SC
Coal
N
CC
S
RP
Caterpillar Advance
Cross Section at Q – Q (Enlarged)

Figure 7. Telechiric mine layout details

should not extend 10 or even 20 miles underground from the access drift provided the long distance roadways were fully reinforced to withstand earth movements. Such earth movements would be much less than with present longwall working systems in view of the fact that the coal removal is replaced by stowage material. There are at present limitations to the mass of coal that can be carried on a single belt but there is no reason why there should not be a number of belts running in parallel bringing the coal up and taking the stowage material down.

Ultimate Possibilities

In the long term it will clearly be necessary to make entirely new developments in mining methods and machinery to take the fullest possible advantage of the fact that men are not at risk. If we can mine coal (i) at very much greater depths than at present down to that at which oil can be drilled, (ii) we can go tens of miles under the sea, then the amount of coal available to us is increased many-fold. Every time that we drill for oil under the North Sea we locate magnificent seams of coal and there is probably as much coal under the North Sea as there is under Britain. These developments will require advances not at present available such as continuously lining a roadway with a thick tube of steel reinforced concrete as it is cut. Ultimately it may be possible to mine coal in a pit completely flooded with sea water.

[illegible]

These brief considerations do I hope confirm the view that coal is the primary fuel of the 21st Century and that we should spend at least as much money on developing ways of getting it out of the ground, without men going underground as we spend on research into nuclear fission and fusion.

Note: these are the personal views of the Author.

Bibliography

For more information on the problems and possibilities of coal mining see *Coal Technology for Britain's Future*, published by Macmillan, ISBN-0-33-19418-7 (1976).

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Mining Without Men Going Underground

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A method for getting coal out of the ground without men going underground (Telechiric Mining) can be developed without the need to discover any new principles. The nuclear industry has already developed remote handling. There is little doubt that if miners could operate the machines necessary to cut and transport coal by remote telechirs from the surface then mining would become a task no more dangerous or unhealthy than, say, operating a power station. It would not be necessary to ventilate the mine or convey men to the coal face every shift. This would mean that a relatively large area could be operated from a single drift or shaft and we could mine further under the sea. Ultimately we might also be able to extend the depth to which we can mine and mine thinner seams.

MINING WITHOUT MEN GOING UNDERGROUND

1. A WORLD ENERGY POLICY

Most of the decisions taken for reasons of political expediency are short-term local decisions. Examples of such short-term decisions are:-

i The closing down of railways and the destruction of agricultural land by building motorways. There is no possible substitute of equivalent convenience to liquid fuel for road transport. Railways are the only system which can run just as well on coal as on oil. Since it will not be possible to electrify all railways and the generation of electricity from coal will always be a very inefficient process there will undoubtedly be, in the next century, if our civilisation survives, a return to coal fired steam locomotives. There is a project in the Department of Mechanical Engineering, Queen Mary College, London University, England, for studying a high efficiency steam locomotive with fluidised bed.

ii The development of a large central electricity generating system based essentially on the use of electricity for such thermodynamic low grade purposes as water heating and space heating. If one burned coal, for example, directly in the home one could achieve these results with an overall efficiency of 80%, the best that can be done with electricity is 25%. There is the further disadvantage of tying-up enormous amounts of capital in large Central Power Stations and Grid Systems which will not last very long. It is quite clear that such a system could not possibly be provided for all mankind because of the resource limitation to set up the Central Power Stations and distribution systems. Central Power stations whether coal fired, oil fired or nuclear fusion or fission are thus only a rich man's toy and in no way a solution to the long-term energy problems.

iii The development of an over-expanded steel industry producing steel for cars which only last a few years and which are incredibly inefficient in terms of fuel consumption. It has been calculated that the energy required for someone to go shopping in a car is several hundred times that which would be used if they went on a bicycle.

If we take a long-term view of the energy problem, even from the point of view of one country alone we see at once that the whole world is interconnected, both in peace and war and that energy policy is inextricably bound up with other problems such as unemployment and arms escalation. The limited number of the parts of the world where oil is available in large quantities and its transport across the world by giant tankers and the need for countries like Japan to pay for their oil imports by exporting manufactured goods is another basic cause of overall world tension. In the Middle East at the present time most of the natural gas associated with the oil is flared to waste because it is not convenient to use it in our hurry to get the oil out. This natural gas has about one-sixth of the value of the oil with which it is associated.

The population of the under-developed countries is growing at about 3% p.a. while that of the developed countries grows at less than 1% p.a. Thus, if the present trend continues, there will be nearly four times as many people in the underdeveloped countries as in the developed ones in 30 years time

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instead of twice as many as at present. In any case the world population will be 8000 million by the year 2010 unless we have a holocaust which destroys hundreds of millions of people.

Another reason why the developed countries cannot hope to solve their problems in the long run is that of unemployment. So far the argument against Ludditism has always been that if the engineers by the use of an ever increasing fossil fuel consumption increased the workers production this could be absorbed by paying the worker more so that he could consume more real goods. It is this author's opinion that this argument has led to an exponential rise of consumption of raw materials and particularly of fuel. However, it has now just about reached the limit set by -

1. The limited world resources of fossil fuel and other raw materials such as pure metal ores.
2. The space factor that one cannot get more than a certain number of cars on the road in a town or more than a certain number of gadgets in a kitchen.
3. The good sense of human beings which eventually makes them resistent to the blandishments of the advertising of new consumer gadgets. The author considers that these three factors mean that a further rise in productivity such as can be produced by robots and microprocessors will cause more unemployment than it creates employment. All those who have studied the matter have concluded that it is degrading for a person to be told that society has no use for their services so that the short-term expedients of paying unemployment money and hoping for a world boom will no longer suffice for more than one or two decades.

If our civilisation is to survive throughout the next century, it is the author's opinion that the following problems must be resolved through a unified effort of all countries.

i The only humane way of levelling off the world's population is to give all the people of the world, within the next generation, a decent standard of living and a decent education so that they can decide, with full understanding, to limit the size of their families.

ii Millions of people are starving while other millions are living a thoroughly wasteful existence in terms of both energy and other raw materials. The gap in standards of living must be essentially eliminated.

iii The average energy consumption in the technologically developed countries is five to six tons of coal equivalent per head per annum (5-6 TCE/cap an). That in the technologically underdeveloped countries is about ½ TCE/cap an while the world average is about 1.8 TCE/cap an. If we are to eliminate the gap between these countries it is not possible for the developed countries to keep their energy consumption at the present level let alone increase it by about 2 or 4% as the growth policies desire. If we kept that of the developed countries at 5½ TCE and brought that of the underdeveloped countries up to this figure while the world population doubles in the next 30 years the gross world consumption of energy would have to come up by a factor of about 6. This is impossible both because of the limitation of the fossil fuel resources and hence of the capital equipment needed to make use of non-fossil fuel energy and because if we depended entirely on coal the atmospheric CO_2 would rise to a disastrous level. One is therefore forced to the conclusion that the only sensible long-term policy for the developed countries is to bring down their energy consumption to about the present world average figure per head, namely 1.8 or 2 TCE/cap an as illustrated in Fig.1. If, at the same time the underdeveloped countries come up to this figure the world average consumption would remain the same as at present so the total energy consumption would be only twice that at present because the population would have doubled.

iv To double the present total world energy consumption rate two things are necessary, first we must regard fossil fuels as a capital resource, that is by the time they are all used we must have invested enough of them in the production of equipment for providing our descendants with the renewable resources, particularly (1) solar energy for the tropic areas (2) biomass, grown, either as a by-product of food or other useful crops, or grown by irrigating the desert with solar distillation (3) the other main long-term source of energy for those areas where the wind is above average will be a very large number of small windmills. In the Mechanical Engineering Department of Queen Mary College, London University we have a project from the Overseas Development Administration to develop a solar steam engine for the tropical areas which could produce 2 kW of electricity and boiling water and sterile water for a village. The boiling water would save them using burnable biomass for cooking and could be stored for evening use.

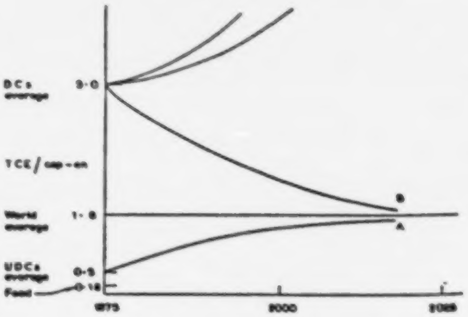

Fig. 1 Present and future energy consumption per head per year.

The second main step which we have to take for stability on the energy situation is to develop a method of mining or recovering coal (and also other solid minerals) without men going underground.

It is certainly clear that coal must play an increasing part in the energy picture of the world as oil and natural gas resources become exhausted. Indeed many people are already speaking about the second coal era when "synthetic natural gas" and synthetic oil are made from coal. Underground mining suffers from the disadvantages that the men have to work in conditions which would be totally unacceptable on the surface in an atmosphere which always contains significant amounts of dust, they have to travel long distances underground every day and finally there is a high level of risk of accidents due to falling roof, explosions of dust or methane and mechanical accidents due to the cramped proximity of men and machines. Thus it seems certain that a solution to this problem of expanding our coal mining is necessary, if the underdeveloped countries are to have the benefits of the Industrial Revolution. This paper is particularly concerned with a proposal which is being looked at at the present time for solving this problem.

2. WORLD AND BRITISH ENERGY RESOURCES

Table 1[1] shows recent estimates of the world's coal resources in millions of tons. The total measured reserves of all kinds of coal are about 11 x 10^{12} tons and this is only the coal under the land areas and at depths suitable to be reached by human coal miners. The total world fossil fuel consumption is equivalent at present to about 7 x 10^9 TCE/year so that the reserves could supply us at our present rate for about 1500 years if we could win them all.

Out of the European coal reserves Britain has as follows (MT ie 10^6T)

Economically recoverable hard coal	Measured reserves all ranks	Total resources
3871	98, 877	162,814

% of world resources	1975 hard coal production	% world production
1.5	127.8	5.3

England has about 1.4% of the world population so that we have just over our fair share of the world's resources and nearly four times that of production. Our peak coal production was 270 M tons in 1913 but our coal production has declined from 230 M tons in 1951 to less than 130 M tons in 1975 because oil has replaced it as our major fuel.

Table II shows the estimated recoverable world resources of natural gas and crude oil in units of 10^9 TCE while Table III compares the various world resources, all in units of 10^9 TCE. These tables show why we shall certainly have to swing back from oil to coal both in Britain as well as in the rest of the world if the oil reserves are exhausted in the next 20-30 years.

TABLE I WORLD COAL RESOURCES AND PRODUCTION[1]

Country	Economically recoverable, hard coal (× 1 M tonnes)	Economically recoverable, lower ranks (× 1 M tonnes)	Measured reserves, all ranks (× 1 M tonnes)	Total resources, all ranks (× 1 M tonnes)	Per cent of world resources	1973 hard coal production (× 1 M tonnes)	Per cent of world production
European and Asian USSR	165 800[1]	107 400[2]	73 204	5 713 681	53·0	536·0	22·4
Total North and Central America	128 320	38 680	377 912	3 045 280	28·2	565·2	24·6
Total Asia	114 668	1677	343 377	1 118 623	10·4	635·3	26·6
Total Europe	41 292	37 676	380 918	620 208	5·8	472·1	19·8
Total Oceania	13 893	10 780	74 604	199 641	1·9	68·6	2·9
Total Africa	12 335	313	36 667	32 029	0·3	74·9	3·1
Total South America	80	1814	5762	14 897	0·1	8·6	0·4
Total World	475 280	219 071	1 297 474	10 751 737	100·0	2360·7	100·0

Primary source: World Energy Conference Survey of Energy Resources, 1974.
Secondary source: World Power Conference Survey of Energy Resources, 1968.
Production data: International Coal Trade, US Department of the Interior, 4 April 1975. Vol. 45.
Hard coal includes anthracite and bituminous coals.
Lower ranks include sub-bituminous, lignite and brown coals.
Total resources include all measured, indicated, and inferred resources.

TABLE II ESTIMATED RECOVERABLE RESERVES OF NATURAL GAS AND CRUDE OIL*† [3]

	Natural gas	Crude oil	Oil shale and tar sands
Africa	8·4	23	4·2
Middle East	15·1	91	38
Asia	3·8	7·6	4·2
Europe	>6·3	>2·1	>4·2
USSR	25·2	14·7	6·3
USA	12·6	10·5	270
Canada	4·2	2·1	137
S. America	2·1	14·7	>2·1
Australia	>2·1	0·4	
World	82	166	460

TABLE III WORLD FOSSIL FUEL RESERVES AND RESOURCES

	Reserves (× 10^9 TCE)	Total resources (× 10^9 TCE)	Resources recoverable by new methods (× 10^9 TCE)
Coal	1300	10 800	21 000[1]
Oil	166	350	700[2]
Natural gas	82	200	500[3]
Shales and tar sands	460	900	10 000[4]
Uranium	17	43	5 000[5]

[1] Assuming telechiric mining is developed to win seams down to 0·5 m thick, at depths up to 3000 m, and undersea distances up to 100 km from the shore.
[2] Assuming means are found of obtaining 90 per cent of all deposits.
[3] Assuming all natural gas is recovered and used from the most remote deposits.
[4] Assuming practical means are found for extracting all oils of significant concentration.
[5] Assuming successful breeder reactors and the extraction of uranium from granite.

3. THE PRESENT SITUATION IN MINING

Since World War II enormous studies have beeen made in mechanisation of long wall coal mining: particularly the rotary drum shearer, the armoured chain conveyor and the advancing hydraulic roof support have increased the output per manshift manifold.

Considerable advance has been made on the automation of the coal cutting process and a device has been made which senses when the cutter is a few centimetres below the top of the seam so that it can be controlled automatically to follow the upper boundary but leave in a firm roof of coal.

However, both mechanisation and automation have associated problems which require strenuous human efforts to maintain production. Among these may be listed -

1. As a direct result of mechanisation the proportion of a coal seam which is mined has gone down from 80% to 40% in 25 years. Thus only half as much of our valuable coal reserves are now mined.
2. Automatic control systems break down more often than human operated systems because the human operator is more adaptable and can take avoiding action or halt the machine before much damage is done. There has been a tendency for breakdowns to be more frequent as automation and mechanisation have increased and a breakdown (for example when the armoured chain conveyor jams) stops the whole output of a coal face until a human operator gets to it, locates the fault and repairs it.
3. A human operator on the spot can take account of a large number of factors in his decisions- for example he can follow the level of the seam by watching the direction of the bands in the coal as well as taking account of the roof sensor. He can deduce coming variations in the seam from variations in the bands and he can communicate other observations to specialists.
4. Increased rates of cutting cause increased dust in the atmosphere and even with very high ventilation rates and thorough water sprays there is a considerable amount of very fine dust at the face.
5. It is not possible to automate roadway cutting and supporting or the operation of assembling machinery conveyors, etc. down the mine.

For these reasons, however far automation and mechanisation is carried out, coal mining will always require the skill and adaptability of trained human operators. Craftsmen, machine operators and Mining Engineers will be needed to make observations and decisions and handle tools and instruments and controls at all points throughout the mine. On the other hand the daily movements of human bodies to and from the coal faces will become an increasing limitation and handicap to the winning of all the coal resources as the most accessible thick seams become exhausted.

There are other solid materials such as asbestos and uranium where the risk of lung cancer is added to that of pneumonoconiosis.

Coal is a very adaptable fuel which can be cheaply stored, and used for making other fuels such as SNG, liquid fuels. It can also be burnt in locomotives and even used to melt steel via gas producers. Thus it is very much more valuable if we can extract solid coal from the ground rather than convert it underground into low grade gas.

It is therefore true to say that by far the most important step which is needed if our civilisation is to survive the next century is to find a way of mining and bringing the greater part of all the coal resources of the world to the surface as solid coal without men going underground. This requires essentially that men on the surface should do all the tasks of erecting, operating, maintaining and repairing machines down the mine and receive all the necessary information.

4. THE PRINCIPLE OF TELECHIRIC MINING

'Telechirics' means hands at a distance. A telechiric system (Fig.2 and 4) consists of a number of human masters sitting in a comfortable control room operating controls and receiving signals connected via cables (or radio) to an equal number of telechirs These consist of a suitable body freely mobile in the hostile environment and carrying arms and hands which can be used by the master to do skilled craft operations. Any job that a miner does at present down a mine for example using tools of all kinds, he can thus do from the surface with comparable skill and dexterity. Most of the work on telechirs has so far been done in connection with the need to carry out skilled operations in radioactive areas, but work in undersea applications is also now being studied.

Fig.2 is a diagrammatic scheme showing the miner sitting at a control chair in the control room on the surface and connected by cable to the telechir which is carrying out a repair operation connecting a hydraulic hose to a mobile pit prop. A small model of a telechir is shown in Figure 3. The telechir consists of a comparatively small body carrying 'arms', 'hands' and 'eyes' (TV cameras) on it and supported by two special 16 spoke wheels connected by a rigid arm with two vertical-axis hinges to a body also supported by two wheels. Thus the stability is produced by the four wheels but the steering is done by surface controlled movement of two hinges. The whole telechir can move through an aperture 0.6 m x 0.6 m. The front part can go into a space inaccessible to the main body. The front part can jam itself against the roof by means of a hydraulic ram when it requires extra stability for an operation. When the man on the surface moves his head the two TV cameras on the telechir body move correspondingly so that he can obtain the impression of three dimensionality by looking all round an object on which he is working.

Normally the Telechir is operated by a miner whose job it is to operate a particular machine down a mine and the telechir operates this machine. However, the controls may be taken over by a skilled mechanic or a mining engineer when the situation down the mine calls for the different expertise. The man in the control chair wears a special pair of spectacles on which he views what is seen by the two TV cameras of thetelechir, but other pairs of spectacles and a single picture on a large screen are also available so that any of the other mining personnel in the control room of the whole pit shows where all the telechirs are located. For some operations on key machines such as changing a pick on a rotary shearer drum the telechiric arms and eyes would not be carried on a separate body but on a strong arm attached to the machine. Separate telechiric 'eyes' (TV cameras) may be fixed close up to the cutting zone so that the miner controlling the movement of the rotary drum shearer can see the bands in the coal as he cuts it. The number of telechirs required to operate a pit would be about one-sixth of the number of men who work down that pit at present because the telechir can be operated by three separate men in shifts on the surface and because the same telechir can be used at different times by people with different skills. All the men controlling the telechirs can, of course, communicate directly with each other.

It is probable that telechirs will always be less dexterous and slowerthan the hands of a skilled craftsman who is actually over the mine. Thus an actual repair job or assembly job would take longer, at any rate until the machines have been re-designed to be most appropriately assembled, maintained and operated by telechirs. However, there are a number of substantial advantages for telechirs compared with human operators on the spot which may be enumerated as follows:-

i The telechir can stay permanently fairly close to the place where its work will be needed and does not require rests or breaks since there can be change of human operator on the surface at any time.

ii It can be designed to move much faster and more comfortably in a confined space than a man crawling on hands and knees. It can also have a faster mode for running, say 15 km per hour. When going a long distance it will probably have to go from one communication plug point to the next in a battery operated robot mode in which it uses its own senses and microprocessor to seek out the next power point. It can have power of 10 or even 50 kW.

iii The eyes and hand and arms can be carried on a body considerably smaller than a man's body and connected to the main body by a controllable arm so that they can get into a working space large enough only for a man's head and arms.

iv The arms can be 10 or more times as strong as the arms of a man or alternatively the main body of the machine can have a built-in fork lift or crane so that it can lift weights of up to one ton for assembly of machinery.

v The hand can either grasp or be replaced by a plug-in-tool capable of continuous rotation in either direction at speed ranging from drilling speeds to the tightening of a nut with a spanner.

vi The machine can carry with it a whole range of special tools far heavier than a man could carry.

vii It can have any number of arms and hands designed for special tasks and these can be operated successively by one man from the surface or simultaneously by several men all of whom are seeing the same task from the same point of view.

viii The possibility of operating one pair of arms and hands and seeing through one pair of eyes by men of different skills as required constitutes a considerable advantage.

ix The fact that all the men who would be working underground are sitting in the same room where they can communicate with each other and know where all the Telechirs are located makes the possibility of dealing with unexpected events very much greater.

x Finally, we have the advantage that the Telechirs do not have to breathe air so that there is no need to ventilate the mine and therefore no fire risk and it is possible to operate a coal seam tens of kilometres away from the access drift because men do not have to go to the face every shift. The telechirs come to the surface for overhaul once every three months, but all the other jobs down the mine are done by the telechirs.

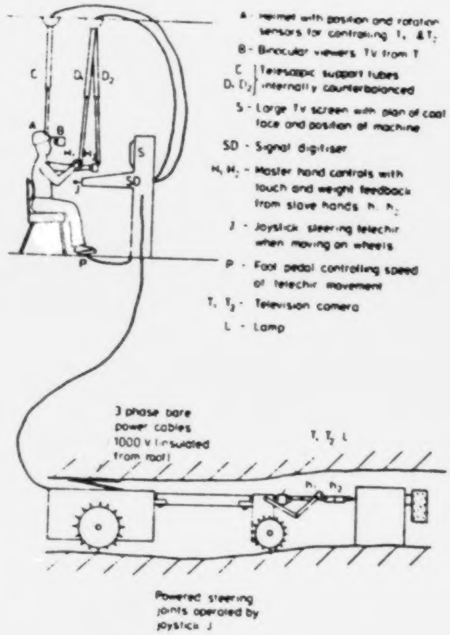
A - Helmet with position and rotation sensors for controlling T_1 & T_2
B - Binocular viewers TV from T
C, D_1 D_2 - Telescopic support tubes internally counterbalanced
S - Large TV screen with plan of coal face and position of machine
SD - Signal digitiser
H_1 H_2 - Master hand controls with touch and weight feedback from slave hands h_1 h_2
J - Joystick steering telechir when moving on wheels
P - Foot pedal controlling speed of telechir movement
T_1 T_2 - Television camera
L - Lamp
3 phase bare power cables 1000 V insulated from roof
T_1 T_2 L
h_1 h_2
Powered steering joints operated by joystick J

Fig 2 Diagram of telechiric mining

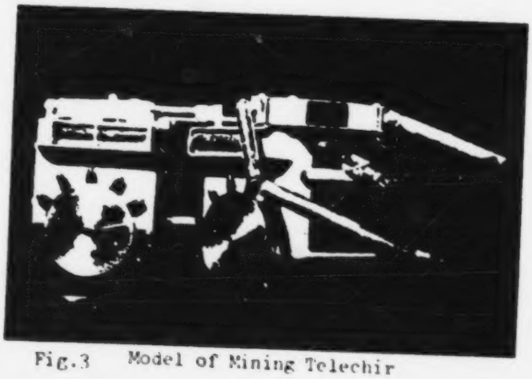

Fig.3 Model of Mining Telechir

5. DESCRIPTION OF A POSSIBLE TELECHIRIC MINE

Fig 4 shows a diagrammatic layout of a mine operating entirely by telechirs and with no man going underground. A single drift is at the centre of the mining area with branches going out from the main roadway to the various coal faces. The whole area could be on a radius of some ten or more miles without any other shafts since men do not have to go to the faces. It is proposed to combine in the single drift a belt conveyor system bringing the coal to the surface although it might be necessary to use a number of belts in parallel as there is an upper limit to the width and speed of the conveyors as at present developed, giving them a limit of 1000 tons/hour when the belt is operated. One conveyor takes the washery refuse down the drift, so that no surface tip is necessary to occupy land. Surface subsidence can also be eliminated by pumping down sand or crushed rock in a pipe or using the refuse conveyor to fill in the whole area behind the working as is already done in

Poland.

Since it will take 20 or 30 years to develop this system we can suppose that there is a parallel development of coal mining machinery, self propelling roof support devices and coal conveying machinery to fit in with the system of telechirs. All present machines have been designed to be erected, maintained, repaired and operated directly by humans whose abilities differ from those of a telechir as discussed in Section 4.

In Fig.4 the diagram shows the layout of a long distance mine for under land work where washery refuse and sand are stowed to eliminate subsidence and roof falls. The aim is to mine some 80% of all the coal. The whole mine is operated in its own atmosphere predominately of methane but with CO_2 and nitrogen and very little oxygen. The coal would be cut on a long wall system by an in-seam self advancing cutter. This cutter would carry the coal conveying system and would fill in 90% of the excavated area behind it, the remaining 10% being supported as a roadway. When it reached the required distance from the main roadway it would swing round a half circle and work back to the main roadway.

The drift would carry the conveyor systems, one for the coal coming up and one for the stowage material going down and would also have a cable railway for machinery and carrying telechirs up and down. At the surface there would be two seals (see Fig.4a) each of which would contain flexible rubber doors brushing on the conveyors and openable doors for the railway when it was used for telechirs or machinery.

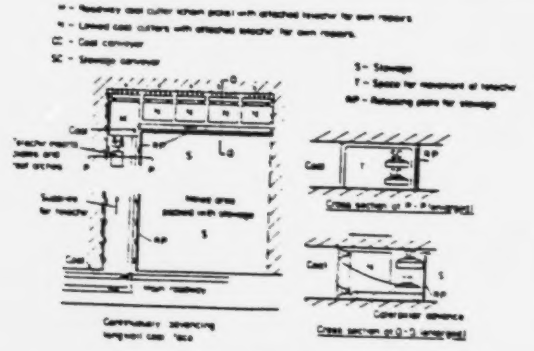

Fig. 4 Telechiric mine layout details

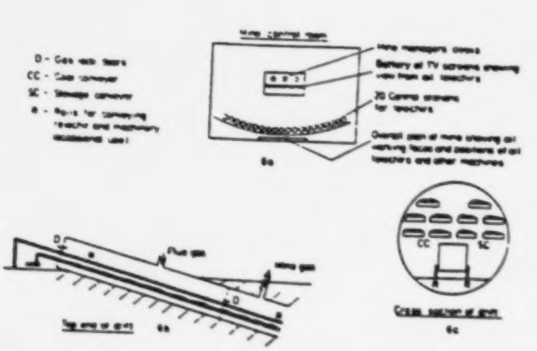

Fig 4a Telechiric mine layout details

The space between the two seals would be filled at a positive pressure with combustion gases to separate the atmosphere and the mine gas. The mine gas would be pumped out from a point a little below the lower seal and would be available as a fuel for surface use. All the machinery would be fully automated, for example the in-seam cutters would be detecting the top and bottom of the seam and moving accordingly and the tasks of the telechirs would be those of monitoring, taking observations, erecting machinery, detecting breakdowns, locating faults and repairing them.

6. CONCLUSION

The author has concluded that the stable future of our civilisation requires that each of the 8000 million people who will be on this earth in the next century should have 1½ to 2 tons of coal equivalent available as energy resources and that in many parts of the world, particularly the developed countries this will have to come mainly from coal. It can also safely be assumed that a comparison with other working conditions will steadily make the work of the underground miner less and less socially acceptable so that the need for a telechir system of mining in some 30 years time will be very strong indeed. There is, therefore, a very strong case that we should begin the research and development needed at once since it will require some 30 years to develop it to a fully workable state unless, of course, one puts the same kind of pressure and resources on to it that have been put on to the space race, weapons of war or nuclear power. In this case it could be obtained in about the same length of time that it took the Americans to land a man on the moon from the first decision to do it, namely 10 to 15 years.

There are three strong arguments for telechiric mining which require no great stretch of the imagination. These are:-

1. The miner will be able to do the same skilled job as he does at present without subjecting his body to the dangers of mining or the health hazard of pneumonoconiosis.
2. All need for daily underground transport of men to and from the face is eliminated so that the waste of time and the expense of men transport systems disappear.
3. There will be no need to ventilate the mine. The primary purpose of ventilation is to enable men to breathe. A telechiric mine would be all electric but as there is no oxygen there would be no fire hazard and machinery need not be guarded against spark emission. This means that the complex double system of ducts and doors to maintain air circulation and the very big fans would be unnecessary. Ventilation does serve a secondary purpose in a mine of reducing the dust and transporting heat from the big machines. Of course it is a very wasteful way of achieving these results to circulate air through the whole mine since the only place where it would be necessary to be free from dust would be where hydraulic or other machinery was being repaired and it would be possible to have a gas filter and fan to produce a jet of dust free gas where it was needed. Heat can be much more cheaply transported by water cooling systems.

There are three longer term possibilities for increasing coal resources which can be mined. These require additional engineering developments which are not yet available but they are likely to be made easier by telechirics.

i Mining coal in very thin seams. At present the thinnest seams mined are 60 to 80 cms, which is the limit down to which the present type of hydraulically operated self advancing roof supports can work. Coal can be ploughed and the seams supported with wood props down to 50 cm. It would be necessary to devise a motor of 100 or more horse power and different types of support and coal cutting machinery. Even in such seams it would still be necessary to have roadways 2 m high for the movement of the machinery.

ii Working coal down to greater depths. At present the deepest seam in Britain is just over 1000 m. Gold is mined in South Africa down to depths of 3000 m but it is not necessary to mine it along horizontal seams in very large tonnages so that the very high temperatures can be overcome by man cooling fans. It is not possible to use the drift system for very great depths and shaft winding is limited to about 2000 m. For greater depths one has to have two shafts of half the length because of the cable weight. There is increased ground movement at greater depths. The telechir does, however, have the advantage over other existing systems that men do not have to stand the temperature, but clearly very much more expensive and newly developed systems would be required.

iii The possibility of working coal 20 or 30 miles from the drift. Here again the telechir has the advantage of making it unnecessary to transport men but there are other problems of maintaining very long underground roadways and transporting coal very long distances underground, which would have to be solved. There is a great deal of coal under the North Sea but it may well be better to sink vertical shafts through an artificial dirt island constructed in the sea. It might ultimately be possible to do this at depths up to 200 ft or even up to the depth of the Continental shelf of 600 ft.

The opinions expressed in this paper are my own and not necessarily shared by the Coal Board.

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1. These tables are from Chapter 4, The Engineer and Energy of the author's book 'The Engineer's Conscience', publ. 1980, Northgate Press.
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ROBOTICS IN MINING - A CANADIAN VIEW

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ROBOTICS IN MINING - A CANADIAN VIEW

Mining, and especially underground hardrock mining, is a latecomer in the utilization of new high technology such as robotics in their operations. It is not that engineers in the industry are unaware of the potential production gains which would be realized with the use of some aspects of high technology in mining. They are certainly aware of the many successful uses of high technology in the manufacturing and processing industry. As well, their knowledge of the successful use of high technology in other sectors is an incentive towards its utilization in mining. There are numerous factors unique to mining however, which impede the rapid introduction of new high technology and robotics in mining:

1. The geometry of mine workings is constantly changing, which forces every operation to be "site specific";
2. The underground environment is extremely hostile to equipment (water, abrassive dusts, materials and temperatures) and tough working conditions make it difficult to design durable eqipment;
3. Mining engineers and the mining industry tend to be technically conservative. A mining engineer feels comfortable with the equipment and methods with which he has experience. Acceptance of new equipment and concepts are generally based on long field trials. The consequence of a bad decision can be disastrous to his, as well as to his company's survival;
4. With regard to the use of robotics in manufacturing and processing, normally the robots used are stationary and the product passes from one to the next in a production line. In mining the working situation is different, with the robot having to approach the product (the working-face or heading).

Studies carried out by the Department of National Defence as well as Energy, Mines and Resources Canada (CANMET) indicate that sensors meeting even military specifications do not stand up to the harsh environment encountered in hardrock mines. New reliable sensors are essential if robotics are to be used in mining. Micro processors, software, hydraulic and mechanical linkage, the other essential eqipment of robotics, have already been used on underground mining equipment and proven their suitability to working the harsh environment. Sensor development for mining needs to be tackled on a priority basis if robots are to be used in mining.

By their nature, and unlike underground hardrock mines, open pit and underground coal mines lend themselves to full automation and semi-robotization.

If advanced technology and robotics are to have wide use in hardrock mining, their use must have a positive impact in terms of higher productivity, lower unit costs, safety and comfort. A conceptual relationship forming between unit costs, and technological and economic limits is indicated in Figure (1). A conceptual relationship between input/output parameters and advancement of technology as applied to mining is indicated in Figure (2).

In 1982, CANMET undertook a study by contract with Robertson Nickerson Ltd., Ottawa, to find out the level of awareness and potential application of robotics in the Canadian mining industry (2). This presentation will address some of the findings of the study.

As part of this study more than one hundred individuals from operating mines, mining equipment manufacturers, universities, research organizations, and hi-tech people in Canada and the USA were interviewed. The objective was not to establish present existing high technology applications, but to explore the mining industry's thinking towards the introduction and use of high technology. As well, the study was to establish the possible roles government agencies, such as CANMET, could play to advance high technology utilization. The question of establishing a viable Canadian mining robotics industry was not part of the study.

The study established that the level of awareness of robotics in the Canadian mining industry is low, if not nil. The concept of developing a robot for use in underground hardrock mining operations was not considered practical by many of the operational personnel surveyed. This view of robotics has been largely influenced by television media reports on the subject and by movie presentations.

Metal Mining in Canada

Canada is one of the leading producers of metal in the world, but maintaining that position is becoming more and more difficult. Because the average grade of ore mined is declining, the tonnage of ore mined in Canada is increasing year by year without comparable increases in mineral products. Approximately eighty-five percent (85%) of Canada's minerals come from hardrock mines (3).

Further, it is evident that the more easily available and readily workable orebodies have already been found. Canada's future Canadian mining engineers will have to face the task of producing a larger part of Canada's minerals economically from lower grade and deeper deposits situated in less accessible locations and under more difficult mining conditions. Because of the working and social conditions that the mining industry can provide in relation to other industries, the mining industry in times of high employment traditionally has difficulty maintaining skilled labour. It is an incentive for the introduction in use of automation and robatization in mines. Progress will have to be made to move mining from the "man-in-the-loop" concept to the "man-out-of-the-loop" concept.

At present, the major productive output from underground mines is from ore bodies at depths less than 1200 m.

Major underground mining methods used in Canadian hardrock mines are the following:

- room and pillar
- cut and fill
- blast hole stoping
- shrinkage stoping
- vertical crater retreat
- sub-level or block caving.

In Canadian hardrock mining, most development and production excavation is achieved by a drilling, blasting and mucking cycle. This is a cyclical process. As a non-continuous process it is not suitable for automation. Because of variability of the fragmentation product, it impedes the automation of related mine operations such as transportation. Continuous mining methods are still very expensive and it is not yet economically feasible to use these to replace the present cyclical methods in underground hardrock mines.

It should be held in mind, however, that equipment in automation does not have to be designed to fit present mining methods. Mining methods preferably, should be modified to new equipment. This approach will provide the service required to design independent units of sophisticated equipment which can be fitted to unconventional mining methods; provided that ground control does not become a problem.

It is the writer's opinion that robotic automation applications in mines will be heavily dependent on the development of new mining concepts. In the survey, the first reaction of mine operational personnel, when the subject of "robots in mining" was raised, was a chuckle or silence. The response in two cases are memorable: "we only use live robots" and "if I suggested a robot for underground operations, they would send me to a nut house". The majority of respondents considered the use of robotics in mines as totally unrealistic (2).

To those with underground hardrock mining experience, these reactions are not a total surprise. After sustained conversation with mine operational personnel on the subject of robotics, however, the interviewers did come away on occasion with some positive and optimistic proposals.

According to the strictest definitions of the word "robotics" there has been no penetration in the Canadian mining industry even at the concept level. There has been a limited use of remote-controlled equipment. The industry would like to see an operation use high technology and micro processor control of operations and equipment which would permit "taking the man out of the loop".

The following is a composite of the reactions of people who were interviewed as part of the study survey on the use of robotics:

First Reaction	Reaction after thinking about robotics potential
No two ore bodies the same	Limited number of mining methods
No repetitive operations	Three or four phase production cycles
Not a continuous operation	Certain processes are bottle necks that could be elminated by more sophisticated and integrated machinery
Environment too harsh for a robot	Environment too harsh for people
Lack of skilled maintenance personnel	There always exists the potential for equipment damage due to operator error.

Surface mines presently constitute 80% of Canada's mine production capacity. These have the advantage of using enormous size equipment thereby permitting easier personnel supervision. Underground mines cannot approach open pit mine productivities, although bulk mining methods are a significant improvement over other available methods. Bulk mine methods are the most amenable to automation and perhaps to robotization, which could further improve productivity.

A number of areas with robotization potential have been suggested by Canadian mining engineers contacted during the study; these are tabulated on page 8-9 of the study. Readers should remember that the suggestions are the result of "wild-card" thinking; no detailed consideration has been given to establish their practicability or feasibility. As well, they represent 1982 thinking. In some instances the ideas have since been put into execution or are under development.

The author thinks that there exists considerable potential, as well as incentive, to develop the means to apply high technology and robotics in the mining of Saskatchewan high grade uranium deposits. Because of their depth, these cannot be economically mined using open pit methods. Equally, because of high radon gas emissions and gamma radiation levels, present conventional mining methods are questionable. In general, the development of sophisticated equipment is required in mining to remove miners from high risk work places. Out of site remote control (OSRC) as well as the robotizing of certain mining equipment are practical as well as essential (see Fig. 1) to the exploitation of some deposits. Canada, because of the Saskatchewan high grade deposits, should be one of the first to undertake such developments because of the unsuitability of present conventional mining methods and equipment. A preliminary concept for mining these deposits is indicated in Figure 3. The development of sophisticated OSRC machines may be an initial step towards robotic units for mining.

It must be recognized that robotics in mining will necessitate technological developments far different from those successfully used in the manufacturing and processing industries. The lack of knowledge of engineers involved in robotics and mining of each others areas is a real impediment to the advancement of the use of robotics in mining. An attempt should be made to bring these two kinds of engineers together so that they can develop a better understanding of each others field needs and capabilities.

Recognizing mine operational requirements and mine environmental conditions, particular attention must be paid to the following factors in developing robots for mine use.

1. Sensors
2. Reliability and robustness
3. Safety
4. Flexibility
5. Intelligence

The above require top R&D priority in any research study on mine robotics. They should be studied vigorously in a suitable underground environment as individual 'elements', and proven suitable, before integrated studies on mine robotics are undertaken.

The robotic industry is on the verge of making major advances in programmed intelligence. The mining environment is so harsh and variable that mining robots will require such intelligence to cope with the array of different variables and situations that will be encountered.

At present, mining engineers in Canada, see robotics in mining as a distant and futuristic visualization, and with very little practical application in the near future. Constant neglect of long-term research on mine robotics because of industry indifference will lead to the importation of robotics equipment to meet Canada's mining requirements. It is realised that, under the present day economic conditions, the development of mining technology for the 21st century is not of the highest priority. It is an area where governmental agencies involved in mining technology research should concentrate a significant portion of their resources and effort.

ACKNOWLEDGEMENTS

The author wishes to thank Dr. J.E. Udd, Director of Mining Research Laboratories (MRL) in Ottawa for permission to write and submit this paper, Mr. G. Larocque, Manager of Rock Mechanics Laboratory, MRL, for editing and valuable suggestions, and Miss J. Byford for processing it on very short notice.

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TABLE I

SUMMARY OF MINING ROBOTIC AREAS OF POTENTIAL
AS EXPRESSED BY THE
CANADIAN MINING INDUSTRY

GENERAL ACTIVITY	SPECIFIC EQUIPMENT APPLICATION	AREAS OF HIGH RESEARCH INTEREST
Drilling	Longhole/DTH	- manipulation of drill rods - programmed drill patterns and sequences - Remote control
	Drill Jumbos	- programmed drill patterns - parallel drilling - remote control - bootleg sensing
xplosives andling	Charging	- Preprogram charging of recognized drill pattern - Automatic ANFO flow sensing - Remote control
	Deactivation	- Basic design
re removal	LHD	- Centralized remote control - Vision systems for longer operating distances
	Gathering Arm Loaders	- Remote control Hagg type loader for hardrock - Sensor development - Integrated systems research
	Train Haulage	- Further development of remote control above ground - Computerized sequencing
	Automatic guided vehicle systems	- Refinement of sensor coils
round onditioning	Scaling	- Mechanization and eventual remote control - Pressure, vision and audio sensor development
	Rockbolter	- Following preset drill pattern - Rock formation analysis - Simultaneous wire mesh installation
	Shotcrete	- Ability to judge work surface and uniformity of mixture
ise boring		- Functional laser guidance systems that are programmable - Complete automation - Flexible machine for a variety of ground conditions
ntinuous ner		- Development of hardrock applicability - More effective impactors - Automation of flexible ground support and in stope handling systems

GENERAL ACTIVITY	SPECIFIC EQUIPMENT APPLICATION	AREAS OF HIGH RESEARCH INTEREST
Miscellaneous	Draw point blockage	- Inexpensive remote system for identifying block and dynamiting
	Pillar removal	- Robotized pillar miner for after mine completion
	Sampling robot	- Development of mobile gas sensor
Futuristic Underground robotics	Telechirics	- Centralized remote control of mining machinery - Long distance remote control
	Continuous	- Continuous mechanical robotic mining systems for all rock conditions free of direct human control
Open pit	Blasthole drills	- Carousel automation - Programmable operating sequences
	Mine trucks	- Automatic driverless control
	Loaders, trucks	- Centralized remote control
Ocean mining	Robot subs	- Manipulator arms - Vision sensors
	Crawler rigs	- Monitoring systems for remote control operation

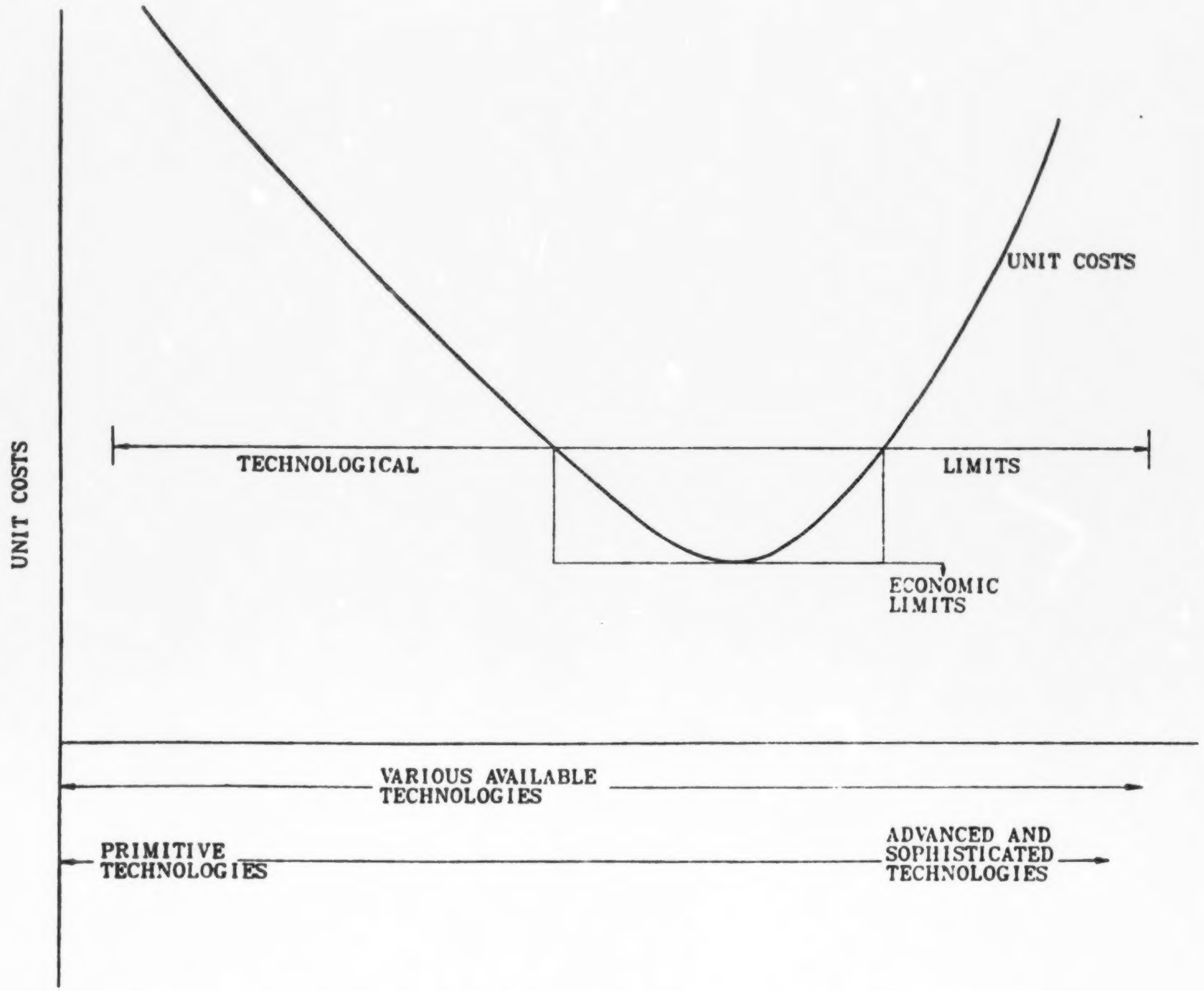

FIG. 1 RELATIONSHIP BETWEEN AVAILABLE TECHNOLOGIES AND UNIT COSTS

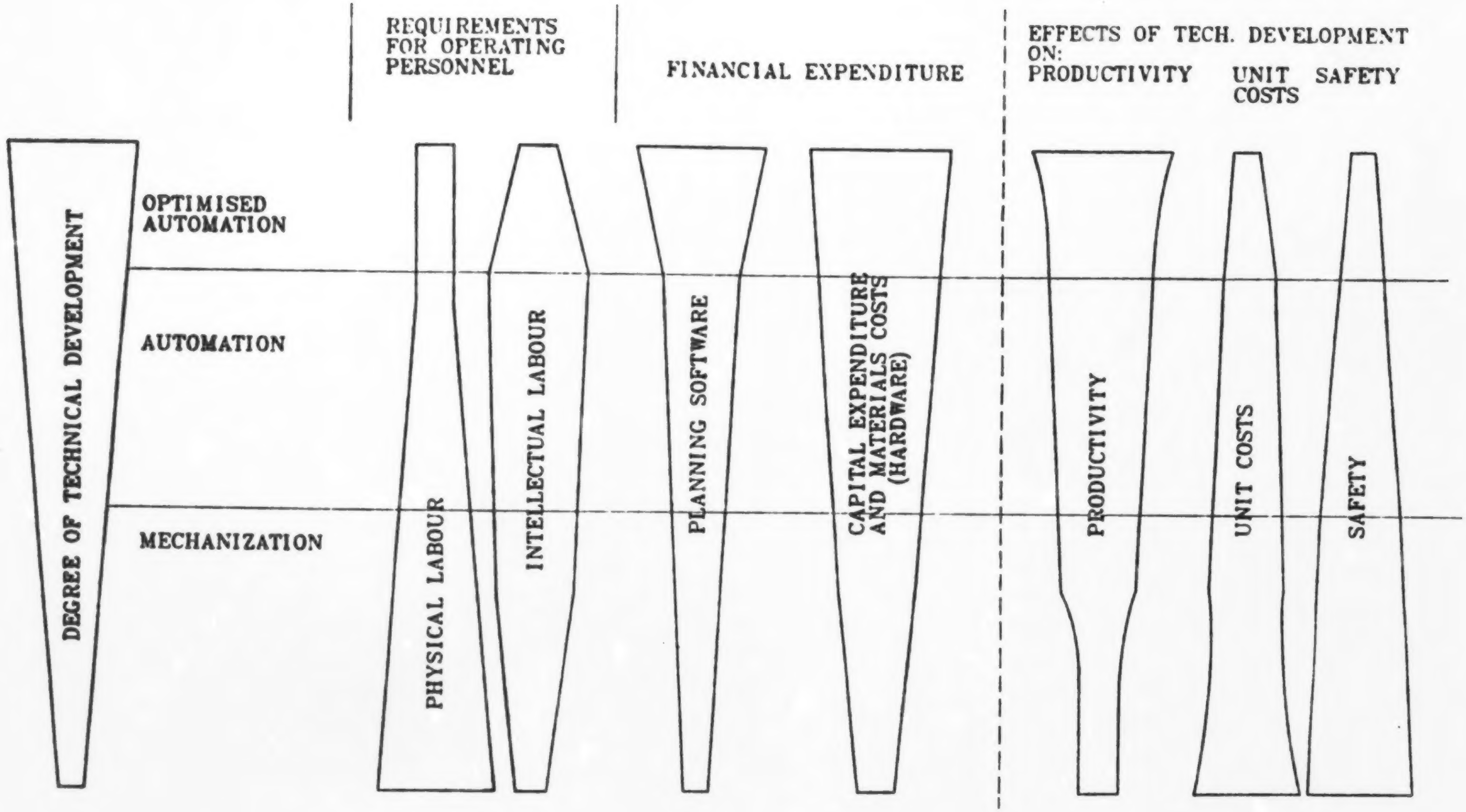
REQUIREMENTS FOR OPERATING PERSONNEL
FINANCIAL EXPENDITURE
EFFECTS OF TECH. DEVELOPMENT ON:
PRODUCTIVITY
UNIT COSTS
SAFETY
DEGREE OF TECHNICAL DEVELOPMENT
OPTIMISED AUTOMATION
AUTOMATION
MECHANIZATION
PHYSICAL LABOUR
INTELLECTUAL LABOUR
PLANNING SOFTWARE
CAPITAL EXPENDITURE AND MATERIALS COSTS (HARDWARE)
PRODUCTIVITY
UNIT COSTS
SAFETY

FIG. 2 EFFECT OF TECHNICAL DEVELOPMENT ON MINING INPUT/OUTPUT PARAMETERS
(SOURCE 1)

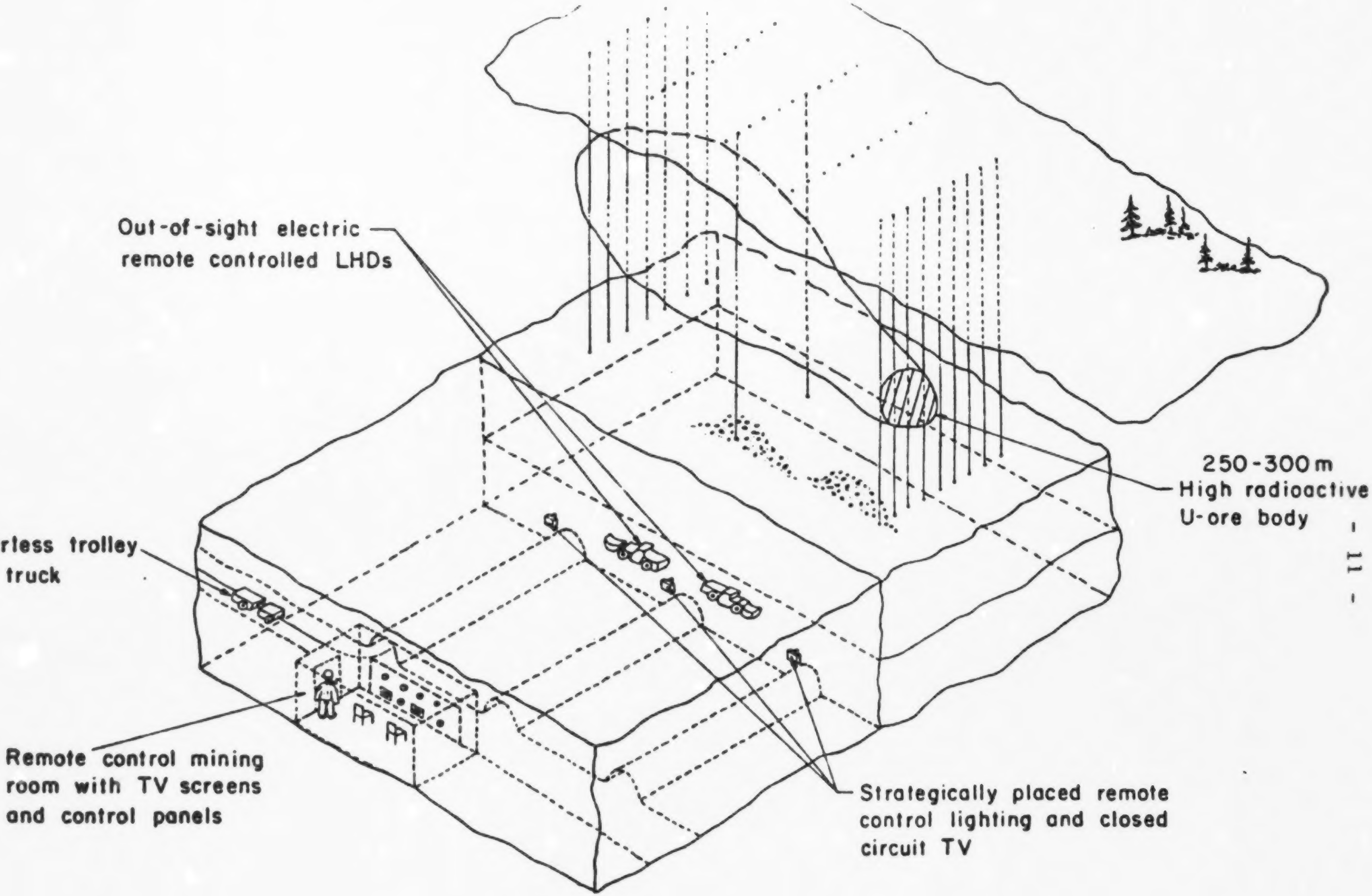
Out-of-sight electric remote controlled LHDs
250-300 m High radioactive U-ore body
Driverless trolley wire truck
Remote control mining room with TV screens and control panels
Strategically placed remote control lighting and closed circuit TV

Fig. 3 Underground hardrock remote mining
(SOURCE 1)

APPENDIX E

INNOVATION IN MINING

Report on the First International Symposium
on Innovative Mining Systems
November 4-5, 1985

Centre for Innovative Mining Systems
Massachusetts Institute of Technology
Cambridge, U.S.A.

The Massachusetts Institute of Technology and The Pennsylvania State University have formed a newly joint venture to create the Center for Innovative Mining Systems. The First International Symposium was held on November 4-5, 1985 at the Massachusetts Institute of Technology.

PROGRAM

AGENDA

Sunday, November 3

4:00 p.m.	Pre-Registration, Cocktail Reception, Royal Sonesta Hotel
8:00 p.m.	Pre-Registration ends

Monday, November 4

8:00 a.m.	Registration, with Coffee and Pastry
9:00 a.m.	Welcoming Remarks Gerald L. Wilson, Dean of Engineering, MIT
9:15 a.m.	Symposium Intentions and Expectations: Introduction by Conference Chairman Carl R. Peterson, Professor of Mechanical Engineering, MIT
9:30 a.m.	International Initiatives Nam P. Suh, Assistant Director for Engineering, National Science Foundation Michael B. Congdon, Office of Energy Technology Cooperation, United States Department of State

10:00 a.m. Developments in Safety

Thomas J. Shepich, Deputy Assistant Secretary,
Mine Safety & Health Administration

James L. Weeks, Deputy Director of Occupational Health,
United Mine Workers of America

10:40 a.m. Coffee Break

11:10 a.m. Overview of Current Major Research & Trends

Kenneth Sacks, Deputy Research Director, Bureau of Mines
United States Department of Interior

Klaus Ahrens, Bergbau-Forschung GMBH,
Federal Republic of Germany

Derek Barham, Head of Automation & Mechanization, National
Coal Board, United Kingdom

12:25 p.m. Luncheon

1:55 p.m. Overview of Current Major Research & Trends

Miklos D.G. Salamon, Director General
Research Organization, Chamber of Mines of South Africa

Jayant Pathak, Head of Mining Methods & Evaluation Group,
CANMET EMR, Canada

2:45 p.m. Coffee Break

3:15 p.m. Panel Discussion: Mechanisms for Industrial and International Collaboration

Moderator: Lee W. Saperstein, Chairman of Mining Engineering Section, The Pennsylvania State University

Ross L. Blackwood, Professor of Mining Engineering, The University of New South Wales

Norman Caplan, Deputy Division Director, Electrical, Communications & Systems Engineering, National Science Foundation

Thomas L. Carr, Director of Mining Research & Development (Ret.), National Coal Board

Howard Clark, Director of Research, American Society of Mechanical Engineers

Helmut Eichmeyer, Mining Department Head,
Technical University of Berlin

M.C. Kossatz, Vice President of Mining, INCO Ltd.

5:45 p.m. Closing Remarks
Carl R. Peterson, Professor of Mechanical Engineering, MIT

6:00 p.m. Adjourment/Cocktail Reception

6:00 p.m. Visit to REMERGENCE Lab (Optional)

Tuesday, November 5

8:00 a.m. Coffee and Pastry, Lobby 9-150

8:30 a.m. Review of Innovations: University Programs
Irving Oppenheim, Carnegie-Mellon University
Roy Nutter, West Virginia University

Martin Robbins, Colorado School of Mines
Jeff Kohler, The Pennsylvania State University

9:20 a.m. Coffee Break

9:35 a.m. Review of Selected Mine Operator Programs & Needs
Review of Equipment Innovations, Capabilities and Trends in Areas of Mining Equipment & Robotics

Concurrent Sessions

Operations

John Campbell, Kerr-McGee Coal Corporation
Charles B. Fly, Hydro-Jet Services Inc.
Eugene Foster, UTD Inc.
Kesari Reddy, Saskatchewan Mining Development Corporation
Bruno Sabels, Consultant, Mannesmann-Demag
Blue Taylor, PCS Mining

Manufacturing

David M. Clonch, Ingersoll-Rand Mining Machinery Group
John C. Harmon, Ingersoll-Rand Mining Machinery Group
Wayne Cusitar, DM Enterprises
William Griffiths, ADMAC Inc.
Manfred Gross, Technical University of Berlin
Gary Marshall, Joy Manufacturing Company
Alex McDowell, Ellicott Machines
Peter Pickerill, Spar Aerospace Ltd.

12:00 p.m. Luncheon

1:25 p.m. General Session - Workshop Orientation Rm. 9-150

WORKSHOP TITLE	LOCATION	LEADER
Establishment of Research Network	Rm. 12-102	Lee Saperstein
Entry Development-Machine Excavation	Rm. 9-451	Chris Bise
Sensing, Monitoring, Diagnostics, Artificial Intelligence	Center Lounge Student Center 2nd Floor	Derek Elsworth
Remote Control, Automation, Mining Systems	Rm. 9-150	Jeff Kohler
Computer Aided Design, Simulation System Development	Rm. 3-471	Bob Frantz
Surface Mining	Lobby 9-150	Barry Phelps
Rock Breakage	Rm. 35-520	Eileen Ashworth

3:30 p.m. Refreshment Break

3:45 p.m. Presentation: Summary of Workshop Findings

4:40 p.m. Concluding Remarks
Carl R. Peterson, Professor of Mechanical Engineering, MIT

5:00 p.m. Program Adjournment

Contact Name and Address for Future Data/Information

Carl R. Peterson
Professor, Mechanical Engineering
The Massachusetts Institute of Technology
Room 3-455A
Cambridge, MA 02139
U.S.A.

A summary of the precedings will be issued in January 1986.

SUMMARY OF WORK BEING DONE IN EACH COUNTRY

Federal Republic of Germany

In the German Coal Mining Industry 100% of the production comes from longwall mining systems and 99% of the faces are mechanized. There are two coal research establishments in the FRG:

- Wetfalische Berggewerkschaftskasse in Bochum
- Bergbau-Forchung in Essen

There are three organizations in Essen. The group consists of six coal companies which comprise of 33 mines producing 85 mt per year. Their budget is 140 million DM/a. The organizations are Steinkehlen-berghauwerein, Bergbau-Forschung GmbH, and Bergwerko-verband GmbH. Steinkehlen-berghauwerein tasks are task formulation, exchange of experience and analysis of results. Bergbau-Forschung tasks are research and development work. Bergwerkaverband tasks are commercialization of patents, test plants and production of own inventions.

The facilities established are testing coal winning machines. The following factors are being investigated.

o testing for theoretical output

o coal proportion - an attempt to decrease the amount of waste presently being mined which amounts to 45% at the present time. Starting points are automatic horizon control and push-out cantilevers

o performance factors

The equipment being investigated are:

- activated ploughs
- shearer
  - high pressure water jets on shearers
  - cutting with vibration tools
- face conveyors
  - conveyors with intermediate drive
  - electric hydraulic drive
  - automatic pre-tensioning control
- face support
  - electric-hydraulic support control
  - positioning of the prop to the coal face
- face-end machines

UNITED KINGDOM

Mr. Derek Barham, National Coal Board, discussed briefly Robotics for Mining under the following headings:

- Locomotion

  Non-wheeled
  - rope/rack haulage
  - legged
  - water mud drive
  - thrust propulsion
  - conformal drive
  - peristaltic drive

  Wheeled
  - rail
  - tire
  - tracked

- Power Supplies

  Self-contained
  - fuel cells
  - compressed air
  - internal combustion
  - battery

  Umbilical
  - surface
  - local static
  - local mobile

- o Manipulators

  Geometry
  - cartesian
  - cylindrical
  - polar
  - anthropomorphic

  Drive
  - pneumatic
  - hydraulic
  - electric

  Grippers
  - fingered
  - attraction

- o Sensors for Manipulation

  Proximaty (non-contact)
  - capacitive and inductive
  - optical
  - acoustic
  - sonar
  - microwave

  Tactile
  - mechanical
  - piezo-electric
  - piezo-resistive

  Image Recognition
  - ULSI
  - illumination

Chemoreceptors

- o Sensors for Guidance
  - position transducers
  - beacons
  - reflectors
  - transponders
  - line systems
  - terrain comparison
  - inertial

- o Guidance Algorithms

System Location

- homing
- following
- evading
- avoiding

Manipular Positioning

- point to point
- continuous path

- o Man/Machine Interface

Display Output

- graphical crt
- liquid crystal
- photo-luminescent
- stereoscopic CCTV
- panoramic display
- voice synthesis

Control Input

- absolute position
- rate
- keyboard
- voice recognition

Ergonomics

o Computer Systems

Hardware

Software

- robot languages
- robot operating systems

o Communications

- internal
- external
- protocol
- speed

o Protection and Safety

- system
- environment
- operator

THE COMMISSION OF EUROPEAN COMMUNITIES (CEC)

Under the Treaty which set-up the European Coal and Steel Community (ECSC), the Commisson of the European Communities is required to provide financial aid for training, rehabilitation, production and research from ECSC funds, which are raised by a levy on the Community's coal and steel production.

Each year the Commission calls for research proposals, fixes budgets for research and development and invites applications for research aid. In response to this call, applications are submitted to the Commission in Brussels and Luxembourg based on projects from formations within the National Coal Board, the Institute of Occupational Medicine, the Health & Safety Executive and universities. In addition to these applications, which are for the most part submitted via the NCB's HQ Technical Department, the Commission also receives applications for aid from other national mining industries within the Community, manufacturers and other bodies, such as universities.

The research aid received by the NCB from the Commission of the European Community is distributed annually through two Directorate-Generals within the framework of six main research programmes, which are set out below.

DIRECTORATE-GENERAL XVII: ENERGY

This Directorate deals with energy supply and demand with European Community and deals with:

- research

- demonstration projects in the field of exploitation of alternative energy sources, energy saving and substitution of hydrocarbons

- pilot, industrial and demonstrative projects in the field of liquefaction and gasification of solid fuels.

DIRECTORATE-GENERAL V: SAFETY AND HEALTH

- The Safety and Health Commission

  - government departments, one for policy, one for technology
  - management
  - trade unions

- Research

  - safety in coal mines
  - health in coal mines
  - ergonomics
  - medical aspects
  - safety and pollution from steel works

The scope and goals of long-range mining research was new systems or machines must integrate with current systems. Any system innovation must also look at the management of the total systems.

Experience with the various financial support methods should be recounted for a) research and b) development.

Manufactures in the high-tech equipment fields find the needs of mining too small when supplying to traditional manufacturers and not financial attractive.

There are strong interfaces between Chief Executives, mine operators and Research and Development but only weak interfaces between equipment manufactures and the other three.

AUSTRALIA

Organization of Collaborative Mining R&D in Australia

Group	Role/Funding
AMIRA - Australia Mineral Industry Research Association	Research broker and manager
ACA - Australia Coal Association	Funded by industry
CSIRO - Commonwealth Scientific & Industrial Research Organization	
NERDDP	The Research Decision
Mining Companies	Process
ARGS	
WAMPRI - Western Australian Mining & Petroleum Research Institute	

There is R&D preceding in innovative mining system in Australia in general systems.

SOUTH AFRICA

South Africa employs 488,000 people in their gold mines. Their mines are not well-mechanized and thus is labour intensified. The gold mines use 20% of the electrical energy of the country. They wish to increase production and provide more safe employment. They have a fairly large budget for technical considerations. One of the aspects being investigated is chilled water reserves for cooling of the deep gold mines.

CANADA

Canada now uses the vertical retreat mining method is some of their mines and this method has reached productivity levels of 100 t/m.s.

Inco. has developed a vertical retreat mining method in one of their mines greatly improving productivity. Productivity has been increased because each aspect of the ore links has been improved.

Mining research activities by the Canadian Government are as follows:

- development;
- drilling;
- explosive loading and blasting;
- secondary blasting;
- ore loading;
- transportation; and
- backfill.

Other aspects being examined are radiation protection, slurry lines, conveyors and blind shaft borers.

The Potash Corporation of Saskatchewan has developed an Optimum Mineral Extraction (OME) concept, where a continuous miner extracts the potash in a longwall fashion. Salt rejects from the plant are placed in a drop pipe and transported from the shaft on the return side of the conveyor and stored in the mined out panel by a flinger. The OME project has reached the demonstration phase.

As part of the OME project, work has begun on the automation of the Marietta miner by improving ore sensing, miner steering, miner tramming (productivity, and mine reliability.

UNITED STATES

The American Society of Mechanical Engineer is firmly committed to the goal of stimulating research and development in the numerous individual disciplines and application areas of mechanical engineering in which it is active.

ASME tackles research in the following manner:

- identify a problem;
- appoint a task force
  - define scope
  - develop a strategy
  - propose methods of solution
  - suggest performers
  - identify responsible parties
  - solicit funding;
- convert to research committee
  - supervise activities
  - assure quality and timelimits
  - provide for discremination of results.

ASME have a number of current projects. The project that is related to the mining industry is Mining and Tunneling.

The universities in the United States have been involved with mining research over the years. Areas that have been researched or are being researched are as follows:

- expert diagnostics of heavy equipment;
- equipment sensors;
- video - mapping;
- accoustic sonar;
- six wheeled vehicle - gasoline and tracking cable;
- computer - map entrance;
- communication;
- micro computer;
- ventilation control;
- method for monitoring systems evaluation;
- peak power shaving;
- face decision support systems;
- longwall research
- geomechanics; and
- material handling

SUMMARY OF TRENDS IN MINING INNOVATION, EQUIPMENT AND ROBOTICS

Research of new mining methods, new equipment, health and safety is being carried out by the countries attending the symposium. These countries were United States, Federal Republic of Germany, United Kingdom, South Africa, Canada, Australia and the European Community.

The trends indicate that there will be fewer production workers in the mine in the future. Monitoring and control from the surface and automation underground will remove many of the workers from the underground mine.

The equipment that could be coming onto the scene are activated ploughs; shearers with high pressure jets; cutters with vibration tools; conveyors with intermediate drive, electric support control, belt blenders in continuous mining; new batteries; flywheel-powered haulage; various mobile bridge conveyors; flexible drills in low coal seams; continuous mining sensors for ore grade, miner steering and tramming; roof bolting and screening machine.

The trend in adaptation to mining systems may be crushing near the face, hydraulic transport (coal slurry), leach mining of coal, borehole mining and longwall auger mining.

Complete robatic mining is believed to be in the distant future, well beyond year 2000.

SUMMARY OF WORKSHOP FINDINGS

Computer Aided Design, Simulation, System Development

- The development technology includes the area of computer assisted drafting, modelling, design optimization and instrument;
- The technology requires a generic approach to problems such as data development;
- The technology needs the ability to compile and optimize complex things such as people, mineral chain and mining;
- Require extensive technical transfer from associated disciplines; and
- Requires time to consider all the aspects.

Remote Control, Automation, Mining Systems

- Definition of the object - general solution vs specific solution;
- The total system approach is required; and
- Evolutionary is generally believed to be the approach to the development of new mining systems not revolutionary. Continuous mining systems must be developed to overcome the present discontinuous systems. Risk sharing is required in developing new technologies.

Sensing, Monitoring, Diagnostics, Artificial intellegence

- Determine the major cost areas in mining. Allow research to be geared to these areas;

- Possible development;

  - machinery - sensors are fine, but interpretation of artificial intelligence is required

  - production - sensing technology not currently available

- Progressive development. Sensing moving towards artificial intelligence;

- Outline requirements in the form of a revised mining system must be determined before decisions on sensing/artificial intelligence to develop strategy is made;

- Philosophy of development - if different sensing options are available what gains would be made;

- Centre should balance a) short and long term goals, b) intergrate development in sensing, monitoring, diagnostics and artificial intelligence; and

- Retain links with industry and discuss development.

Surface Mining

- Goal is to have continuous mining units, instead of the current cyclic operation. This could be in the form of automatic machines using monitoring and central control;

- Better use could be made of current technology; and

- Training managers at all levels could be eventually lead to above steps.

Rock Breakage

Rock breakage goals are:

- Short term;
  - improve current technology
  - water jets
  - explosure
  - primary crushing near face

- Long term;
  - tensile breakage of rock (currently use compression)
  - microwave
  - ultrasonics
  - laser
  - mechanical drill and pull
  - crack propogation
  - freezing

- Use flaws and discontinuities to decide where to drill i.e., intelligent rock breakage; and

- learn language of rock - material source research;
  - look at rock grain interfaces of selectively chosen grains
  - use of chemicals to break cohesion - accelerate weathering process.

Research Network

- Research network can be "hub" and "spoke" versus total interaction;
- Should research be only researchers or between researchers and industry?;
- A network must not be cumbersome or it will collapse;
- A "champion" is called for to develop a research network but a "champion" can limit the network scope by his own interest;
- The objectives of a symposium is to communicate outcome to industry; and
- Before we create a large network we must walk before we can run.

Entry Development - Machine Excavation

Goal is to develop current technology of entry development - machine excavation to increase productivity by 25-50%. The aim is to have a continuous system but the constraints are maintenance, team requirements, legal restraints of roof bolting. The aim should also be to match longwall and development rates.

The needs that were defined were:

- reduce exposure at face; and
- reduce number of entries.

CONCLUSIONS

- New technology in the mining industry will come forth by evolutionary means and not revolutionary;
- Goals must be set by the mining industry and not by researchers;
- One of the goals would be a truly continuous and remote control (automation) in the coal mining industry; and
- These established goals can be reached by sustained progress in developing the required technology.